CERES Cloud Working Group Report

CERES Science Team Mtg., Virtual#3, 8-10 May 2021

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B. Scarino (cal, Tskin, GEO), F-L. Chang (CO2, corrk), Cecilia Wang (machine learning)
E. Heckert (web), B. Shan (GEO), Churngwei Chu (web), Zhujun Li (val)

SSAI, Hampton, VA

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P. Yang (ice models), Texas A& M University

X. Dong, B. Xi, (validation), University of Arizona

Thanks to Dave Doelling and his TISA/calibration teams!

Cloud Working Group Objectives

Produce pixel-level cloud properties from LEO & GEO imager radiances

- Include cloud mask, thermodynamic phase, optical depth, effective radius, temperature, height, etc.
- Used by other WG's to convert measured radiances to radiative fluxes, to compute surface fluxes, and to improve the time interpolation of radiative fluxes.
- Must be as spatially and temporally consistent as possible across platforms in order to minimize discontinuities in the CERES CDR
- Must be inferred at high resolution within coarser CERES footprints even under the most difficult conditions (e.g. at night, over snow/ice, in the presence of thin cirrus and heavy aerosols)

Topics

- Publication's update
- Data Processing Status
- VIIRS Ed1b consistency with MODIS Ed4
- Progress with Terminator/Nighttime Clouds for future editions

CERES Cloud-related Papers

Edition-4 References (https://ceres.larc.nasa.gov/science/publications/)

ED4 CALIBRATION	Sun-Mack et al. (2018), IEEE Trans. Geosci. Remote Sens., 56, 6016-6032, doi:10.1109/TGRS.2018.2829902
ED4 CLOUD MASK	Trepte et al. (2019) IEEE Trans. Geosci. Remote Sens., doi: 10.1109/TGRS.2019.2926620.
ED4 RETRIEVALS	Minnis et al. (2020) IEEE Trans. Geosci. Remote Sens., doi: 10.1109/TGRS.2020.3008866
ED4 VALIDATION	Yost et al. (2020), IEEE Trans. Geosci. Remote Sens., doi: 10.1109/TGRS.2020.3015155.

Other Recent Edition-4 Related Papers (2021)

Chen, H., Schmidt, S., King, M. D., Wind, G., Bucholtz, A., Reid, E. A., Segal-Rozenhaimer, M., Smith, W. L., Taylor, P. C., Kato, S., and Pilewskie, P.: **The effect of low-level thin arctic clouds on shortwave irradiance**: evaluation of estimates from spaceborne passive imagery with aircraft observations, Atmos. Meas. Tech., 14, 2673–2697, https://doi.org/10.5194/amt-14-2673-2021, 2021.

Kang, L., Marchand, R. T., & Smith, W. L. (2021). **Evaluation of MODIS and Himawari-8 low clouds retrievals over the Southern Ocean** with in situ measurements from the SOCRATES campaign. Earth and Space Science, 8, e2020EA001397. https://doi.org/10.1029/2020EA001397

Rybka, H., Burkhardt, U., Köhler, M., Arka, I., Bugliaro, L., Görsdorf, U., Horváth, Á., Meyer, C. I., Reichardt, J., Seifert, A., and Strandgren, J.: The behavior of high-CAPE (convective available potential energy) summer convection in large-domain large-eddy simulations with ICON, Atmos. Chem. Phys., 21, 4285–4318, https://doi.org/10.5194/acp-21-4285-2021, 2021. **Model Evaluation**

Benjamin, S. G., E. P. James, M. Hu, C. R. Alexander, T. T. Ladwig, and J. M. Brown, S. S. Weygandt, D.D. Turner, P. Minnis, W. L. Smith Jr., A. Heidinger, 2021: Stratiform **Cloud-Hydrometeor Assimilation** for HRRR and RAP Model Short-Range Weather Prediction. Mon. Wea. Rev., in review.

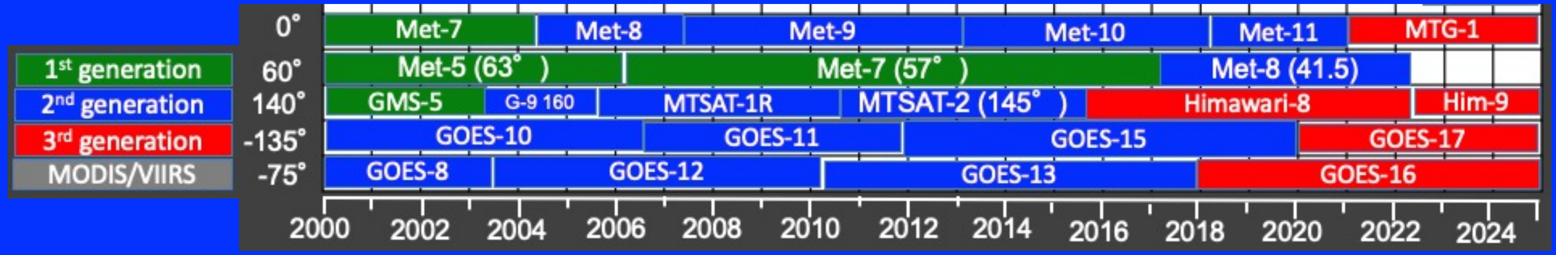
In Review

Painemal, D., Spangenberg, D., Smith Jr., W. L., Cairns, B., Moore, R., Minnis, P.: **Evaluation of satellite retrievals of liquid clouds** from GOES-13 Imager and MODIS over the midlatitude **North Atlantic during NAAMES campaig**n , JGR, in review, 2021.

Dong, X. and P. Minnis, 2021: Chapter 8: Stratus, stratocumulus, and remote sensing, In Fast Physics in Large Scale Atmospheric Models: Parameterization, Evaluation, and Observations, Y. Liu, P. Kollias, and L. Donner, Eds., AGU-Wiley Publ., tentatively accepted.

Clouds Processing Status (GEO)

21 different GEO satellites processed thru March 2021



1st generation satellite

Satellite	Channels (µm)
MET-5	0.6, 11
MET-7	0.6, 11
GMS-5	0.6, 11

3rd generation satellite

Satellite	Available Channels (µm)
GOES-16	0.6, 3.9, 6.7,11, 12, 1.6, 8.7, 13.3
GOES-17	0.6, 3.9, 6.7,11, 12, 1.6, 8.7, 13.3
HIMAWARI-8	0.6, 3.9, 6.7,11, 12, 1.6, 8.7, 13.3

- CERES GEO approach in Ed4 utilizes as much available spectral information as possible to help improve accuracy and consistency with MODIS
- Results in some inconsistencies across GEO platforms (due to different algo's) which are mitigated to some extent in downstream products by other WG's
- Now in an era with MODIS-like imagers providing global coverage but this is leading to some new artificial trends in Ed4 after 2016
- Goal for Ed5 is to better homogenize the approach used for all GEO's

2nd generation satellite

Satellite	Available Channels (µm)
GOES-8	0.6, 3.9, 6.7, 11, 12
GOES-9	0.6, 3.9, 6.7, 11, 12
GOES-10	0.6, 3.9, 6.7, 11, 12
GOES-11	0.6, 3.9, 6.7, 11, 12
MTSAT-1R	0.6, 3.7, 6.7, 11, 12
MTSAT-2R	0.6, 3.7, 6.7, 11, 12
GOES-12	0.6, 3.7, 6.7, 11, 13.3
GOES-13	0.6, 3.7, 6.7, 11, 13.3
GOES-14	0.6, 3.7, 6.7, 11, 13.3
GOES-15	0.6, 3.7, 6.7, 11, 13.3
MET-8	0.6, 3.9, 6.7,11, 12, 1.6, 8.7, 13.3
MET-9	0.6, 3.9, 6.7,11, 12, 1.6, 8.7, 13.3
MET-10	0.6, 3.9, 6.7,11, 12, 1.6, 8.7, 13.3
MET-11	0.6, 3.9, 6.7,11, 12, 1.6, 8.7, 13.3

Clouds Processing Status (MODIS & VIIRS)

CERES-MODIS Edition 4	*Aqua: Jul 2002 – Mar 2021 (~18.5 y)* *Terra: Feb 2000 – Mar 2021 (~21 y)*	• ***Uses frozen Ed4 cloud codes delivered in 2013*** • ***MODIS Collection 5 radiances thru Feb 2016,*** • ***MODIS Collection 6.1 March 2016 – present and scaled to C5 for consistency over entire record*** • ***Terra-MODIS normalized to Aqua-MODIS (Sun-Mack, et al. 2018)***
CERES-VIIRS Edition 1A	*SNPP: Jan 2012 – Mar 2021 (~9 y)* *NOAA-20: Jan 2018 – Mar 2021 (~3 y)*	• ***Uses VIIRS Ed1A cloud code*** • ***SNPP uses forward processing calibrations (C1 radiances), not scaled to MODIS; has discontinuity ~2016 due to a calibration update by SIPS*** • ***N20 uses C2 radiances and scaled to MODIS C5***
CERES-VIIRS Edition 2A	*SNPP: Jan 2012 – May 2014 (~2.5 y)*	• ***Uses VIIRS Ed1A cloud code*** • ***Uses C2 radiances and scaled to MODIS C5***
CERES-VIIRS Edition 1B	*NOAA-20: Jan 2018 – Dec 2018 (~1 y)* *May 2020 – Aug 2020 (~3 m)*	• ***Uses new version of VIIRS cloud code (temporary continuity version until Ed5 is released)*** • ***Fills Aqua-MODIS gap in Aug 2020***

Development of Consistent Cloud Properties from MODIS and VIIRS to Extend the CERES CDR

- Since Terra and Aqua are nearing end of life and begin drifting in 2021 and 2022, the CERES CDR will transition from Aqua to NOAA-20.
- CERES next major edition (Ed5) is being developed specifically to accomplish this as seamlessly as possible without discontinuities.
- The Ed5 cloud algorithms are in development with the goal to provide consistent cloud properties across satellite platforms (MODIS to VIIRS, and improved GEO) using more consistent algorithms and spectral bands than currently employed.
- In the meantime, NOAA-20 data are now needed to fill the Aug 2020 Aqua gap (spacecraft anomaly) and to continue CERES data products once Aqua drifts beyond tolerance and until Ed5 is delivered and processed to current time. Thus, an intermediate continuity approach is needed.
- VIIRS Ed1A clouds are not ideal for this as the algorithm was designed 6+ years ago with some consideration for consistency with MODIS Ed4 but it also included algorithm improvements to improve accuracies.

As a result, Ed1A and Ed4 cloud properties have some significant differences

Introducing VIIRS Ed1B Clouds for NOAA-20

While Ed5 development continues, objective here is to identify and implement relatively simple/quick changes to VIIRS Ed1A algorithm that would provide cloud properties that are more consistent with MODIS Ed4

Based on intercomparisons between VIIRS (Ed1A) and MODIS (Ed4) cloud properties, the following changes were made in Ed1B for N20 to address:

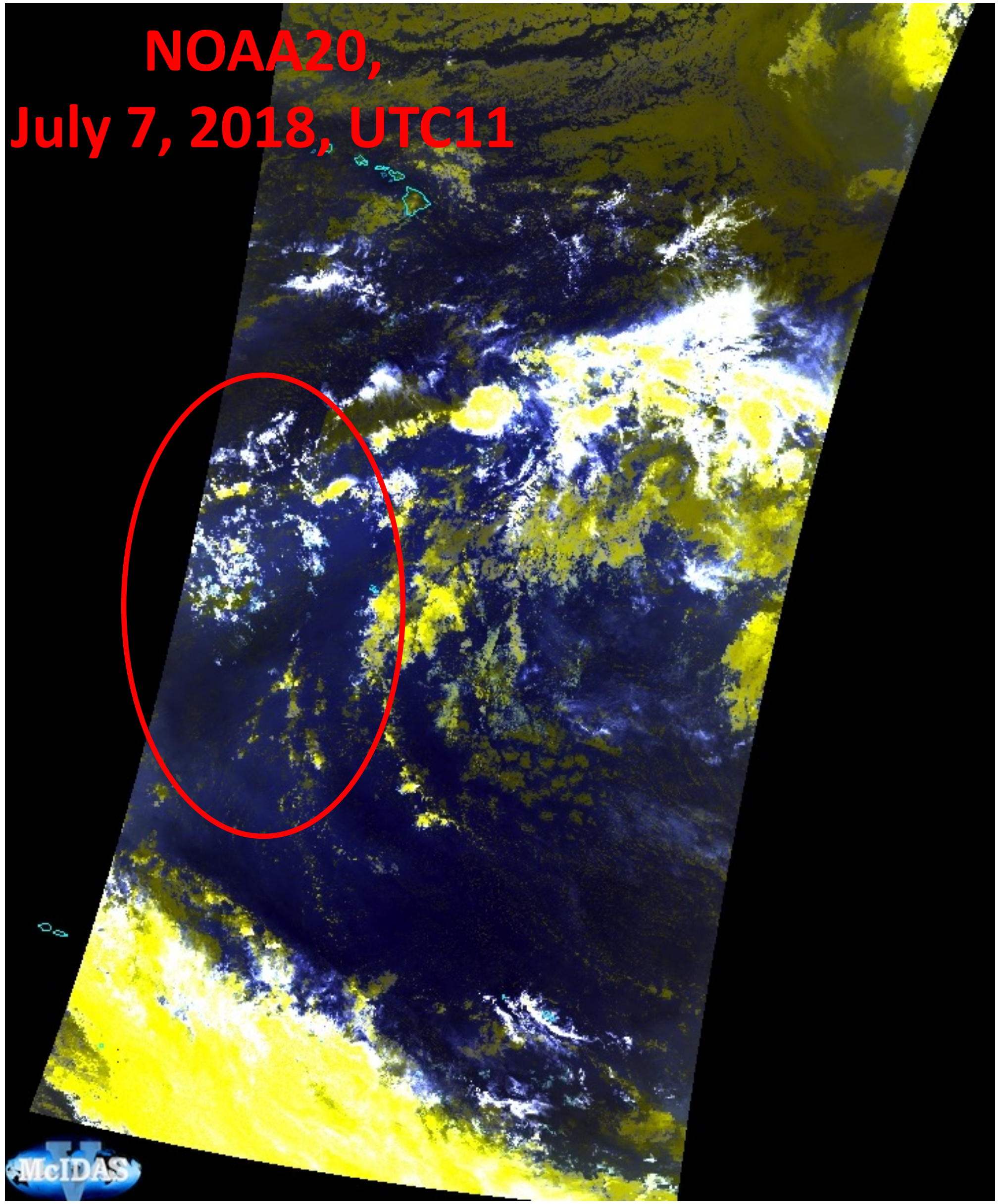
1. **Non-polar nighttime cloud fraction differences**
   - Modified the nighttime cloud mask to increase clouds over tropical ocean and reduce clouds over non-polar land area
2. **Polar daytime and nighttime cloud fraction differences**
   - Ingested a CrIS/VIIRS fusion data product that provides a WV and CO2 channel for VIIRS (see Bryan Baum talk on Thursday)
   - Modified the polar cloud mask algorithm to use CO2 and WV channels as in Ed4
3. **Cloud optical property differences in polar regions**
   - Replaced the VIIRS 1.24 um and 3.7 um reflectance cloud models and parameterizations with those from Ed4 (Ed4 models have interpolation bug and other inconsistencies)

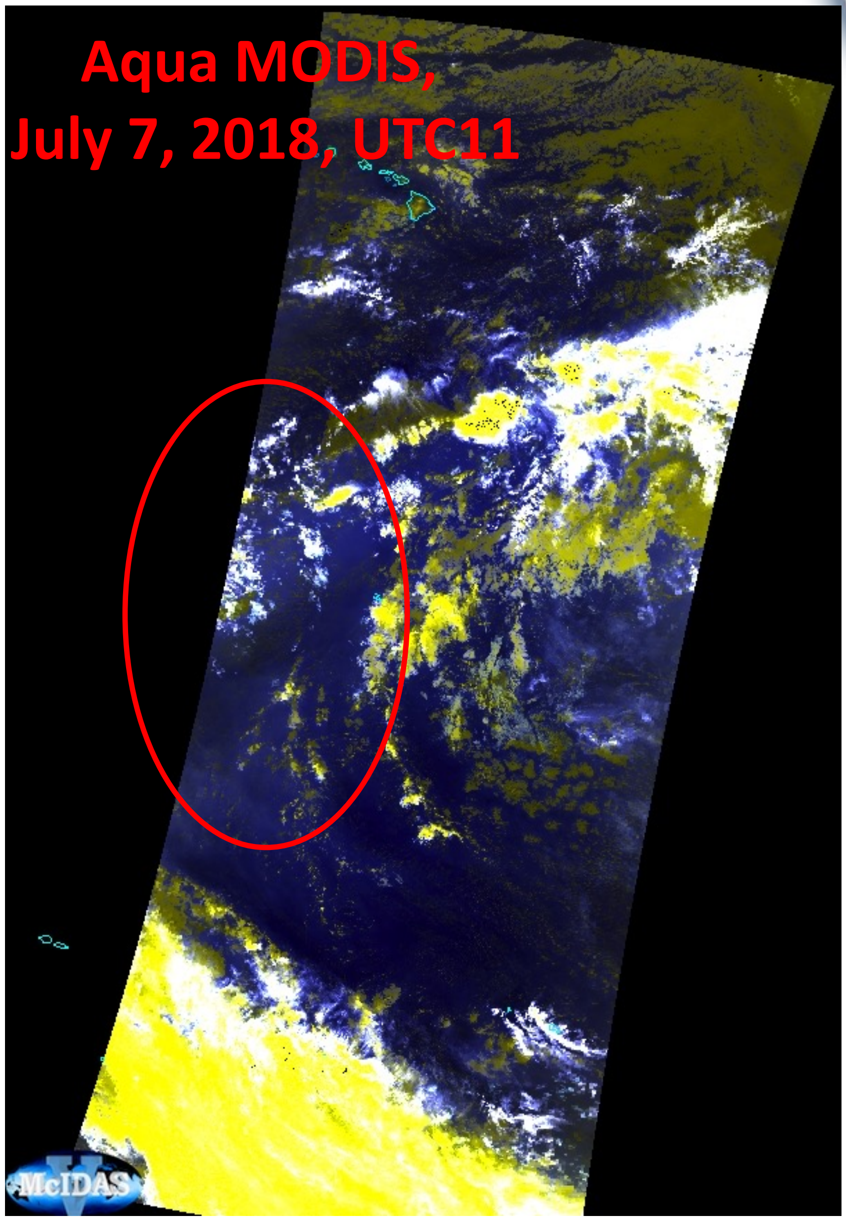
1. Reduce non-polar nighttime cloud fraction differences

Modified the nighttime cloud mask in order to increase VIIRS clouds over tropical ocean and reduce clouds over non-polar land area

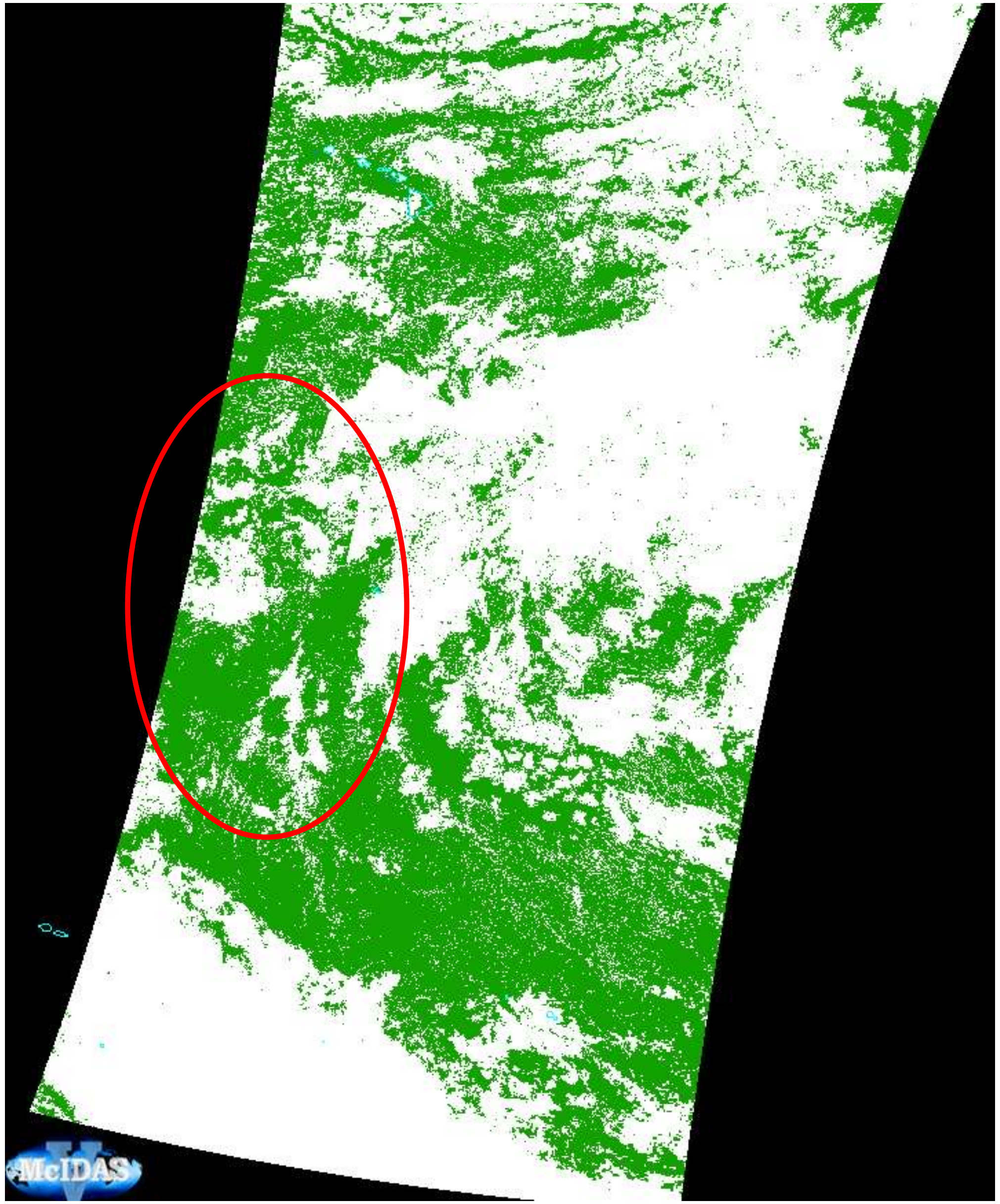
Nighttime Tropical Ocean:

Ed4 MODIS overdetects thin cirrus
Ed1A cloud mask adjusted to fix this (reduce Ci too much)
Ed1B cloud mask adjusted to agree better with MODIS

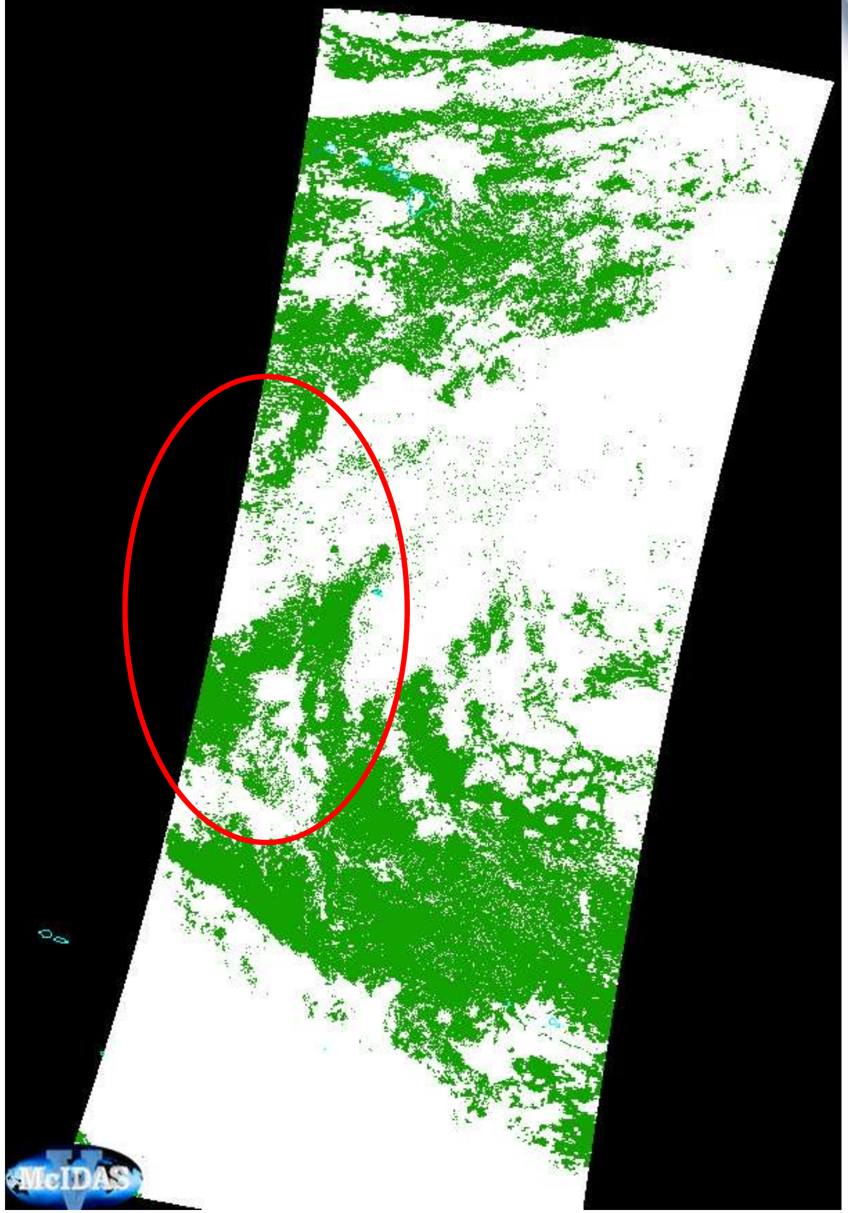




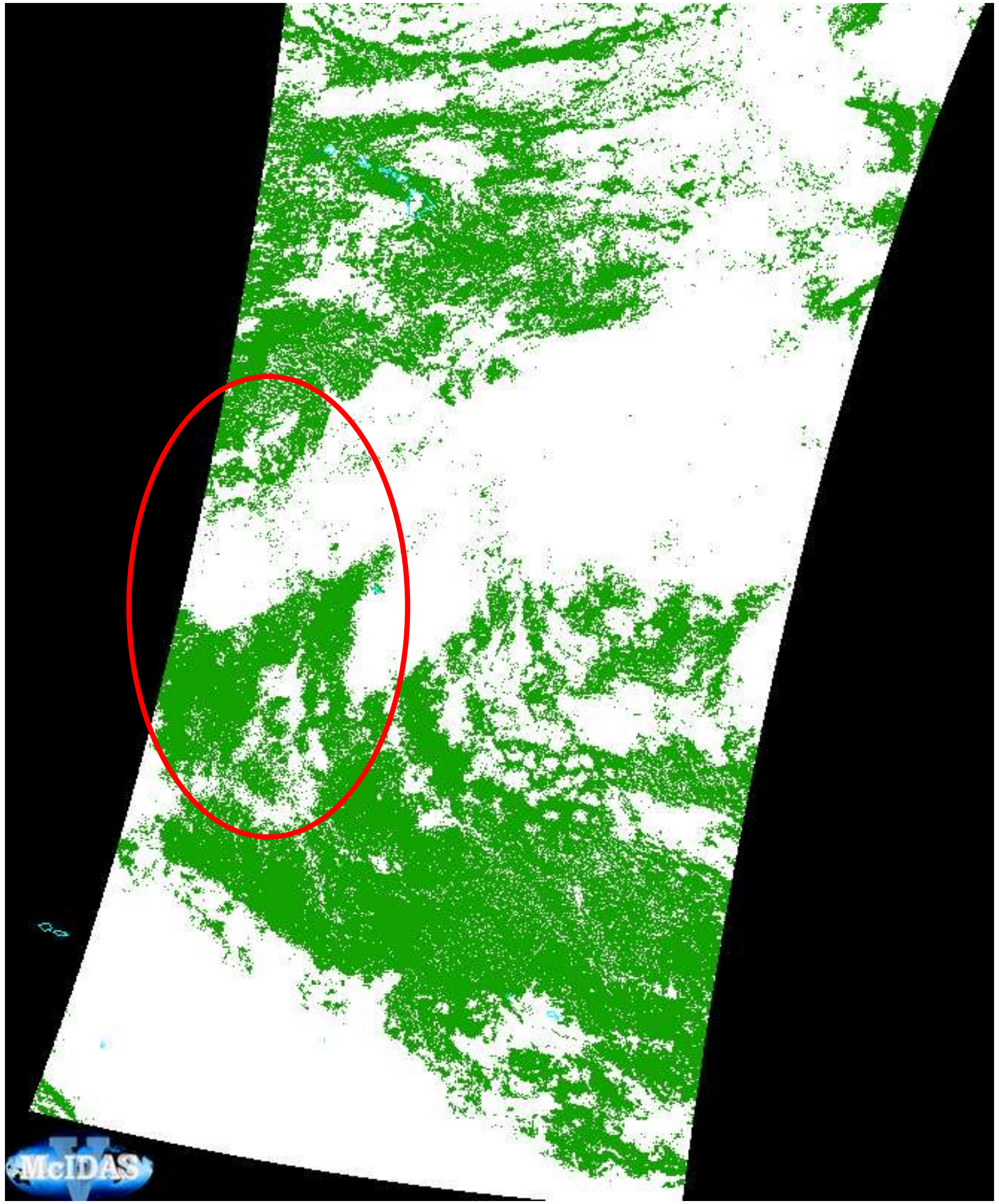
NOAA20 VIIRS
Ed1A Mask



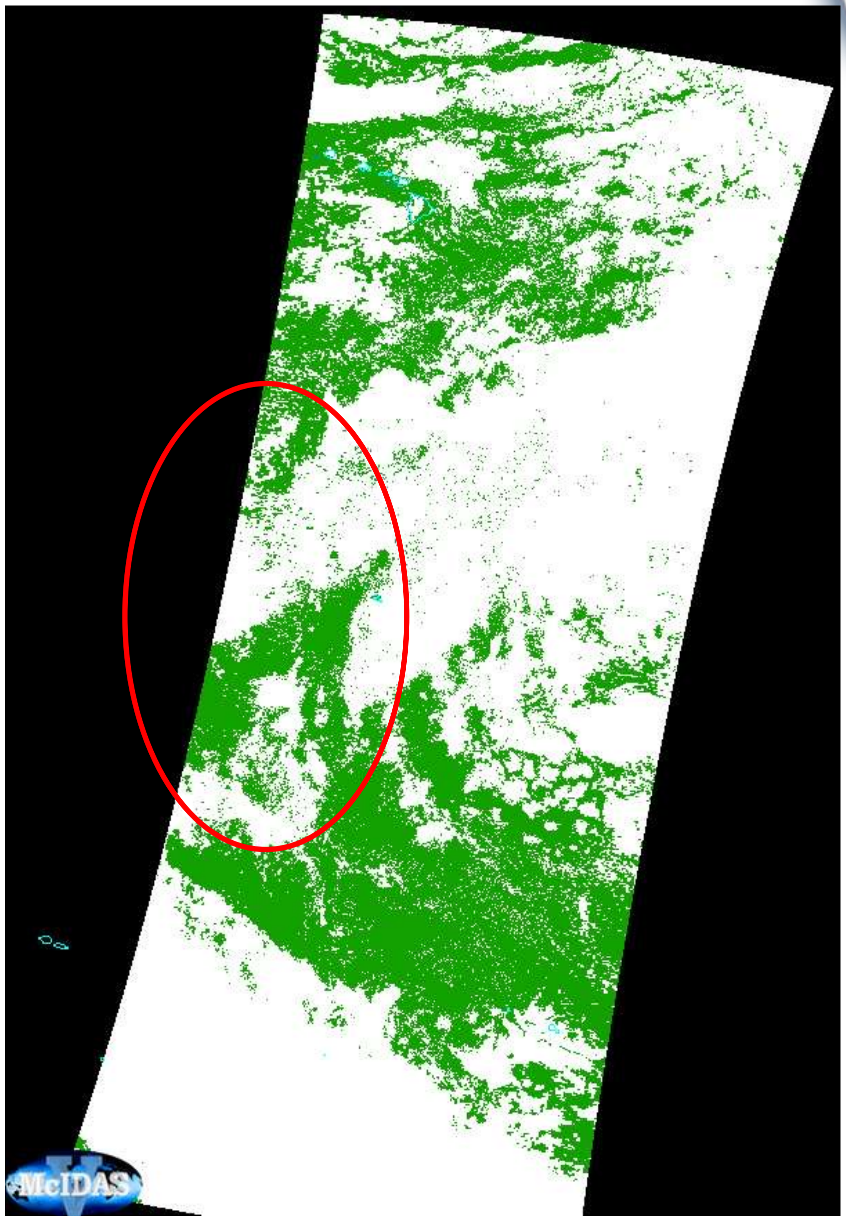
Aqua MODIS
Ed4 mask



NOAA20 VIIRS Ed1B Mask

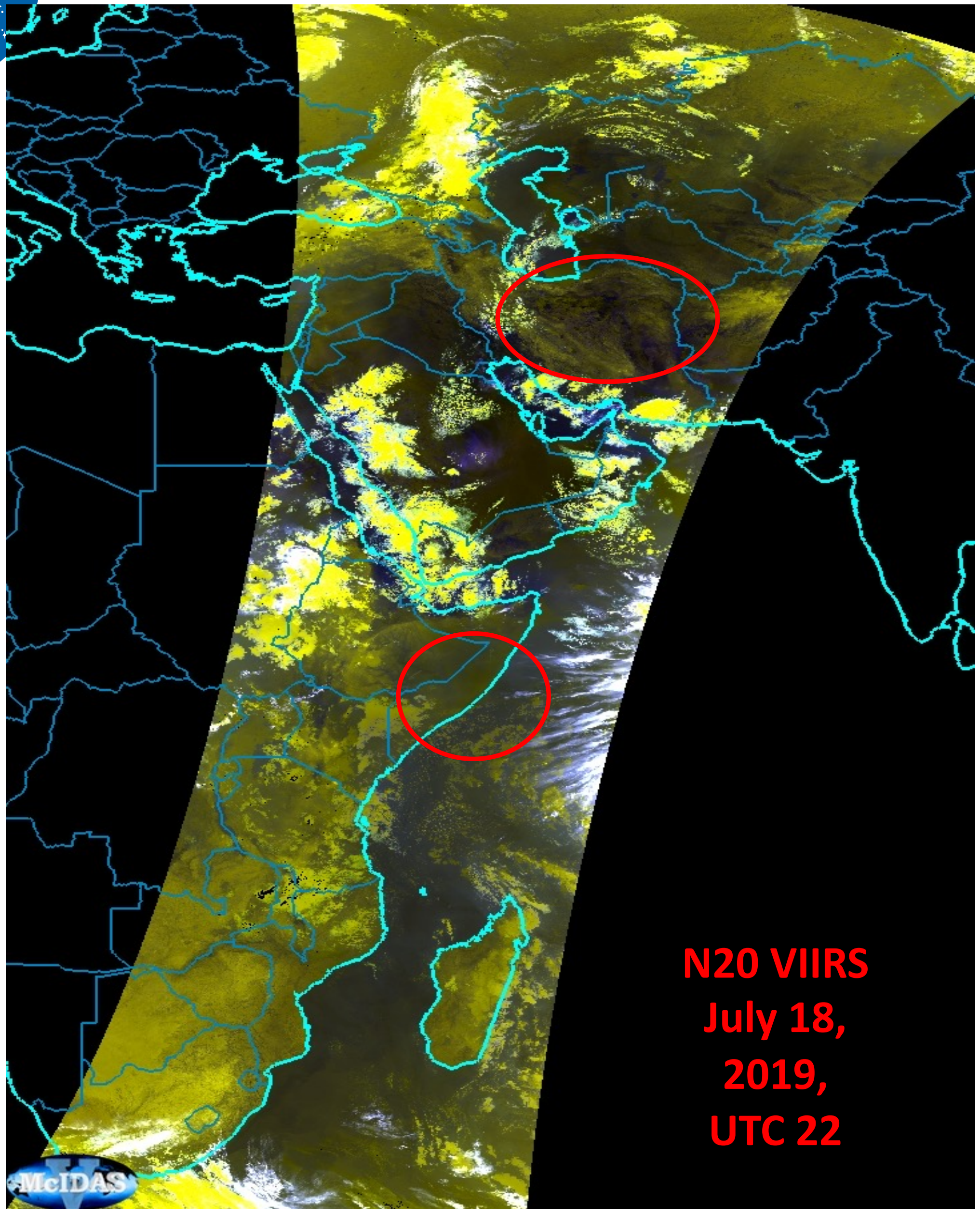


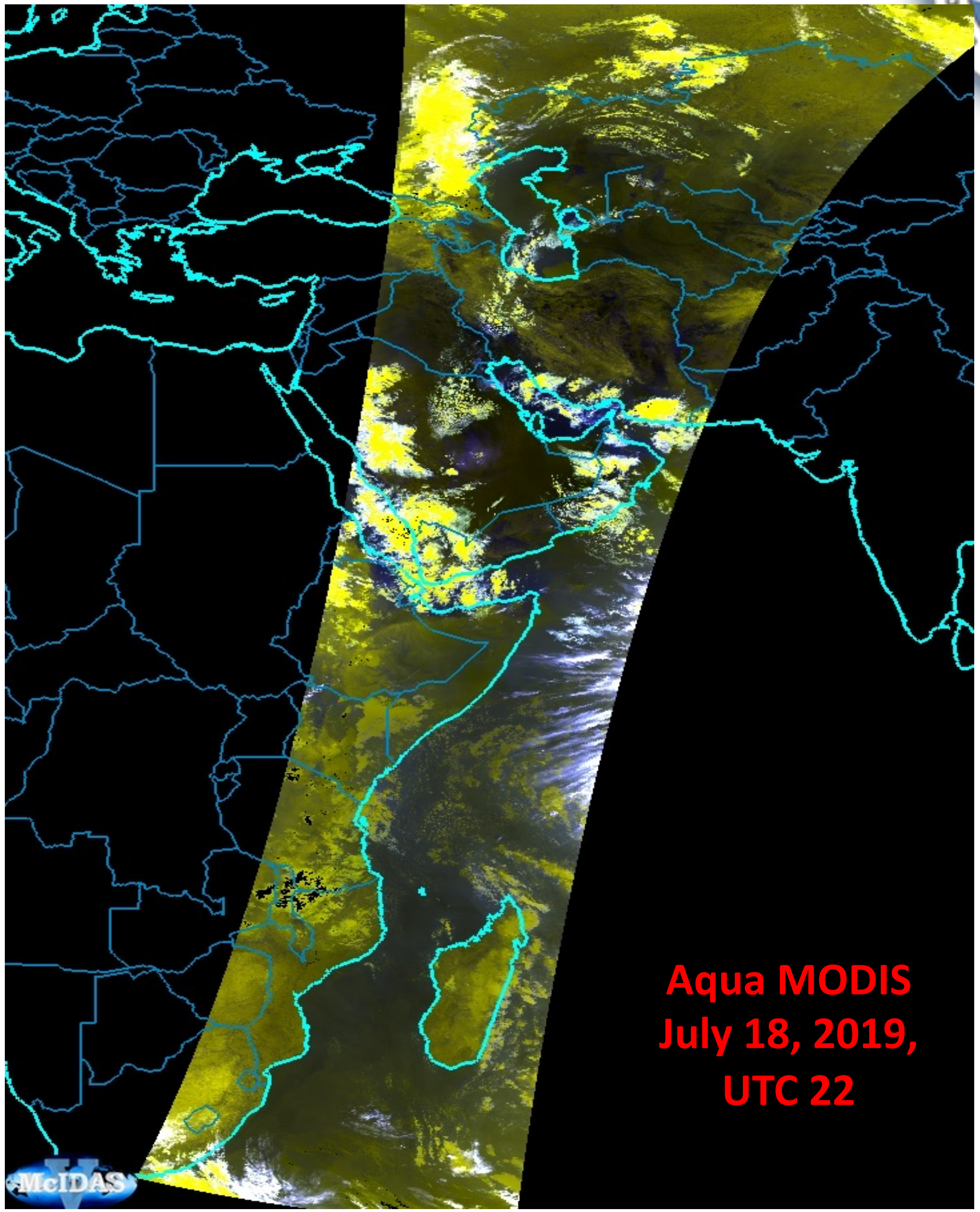
Aqua MODIS Ed4 mask



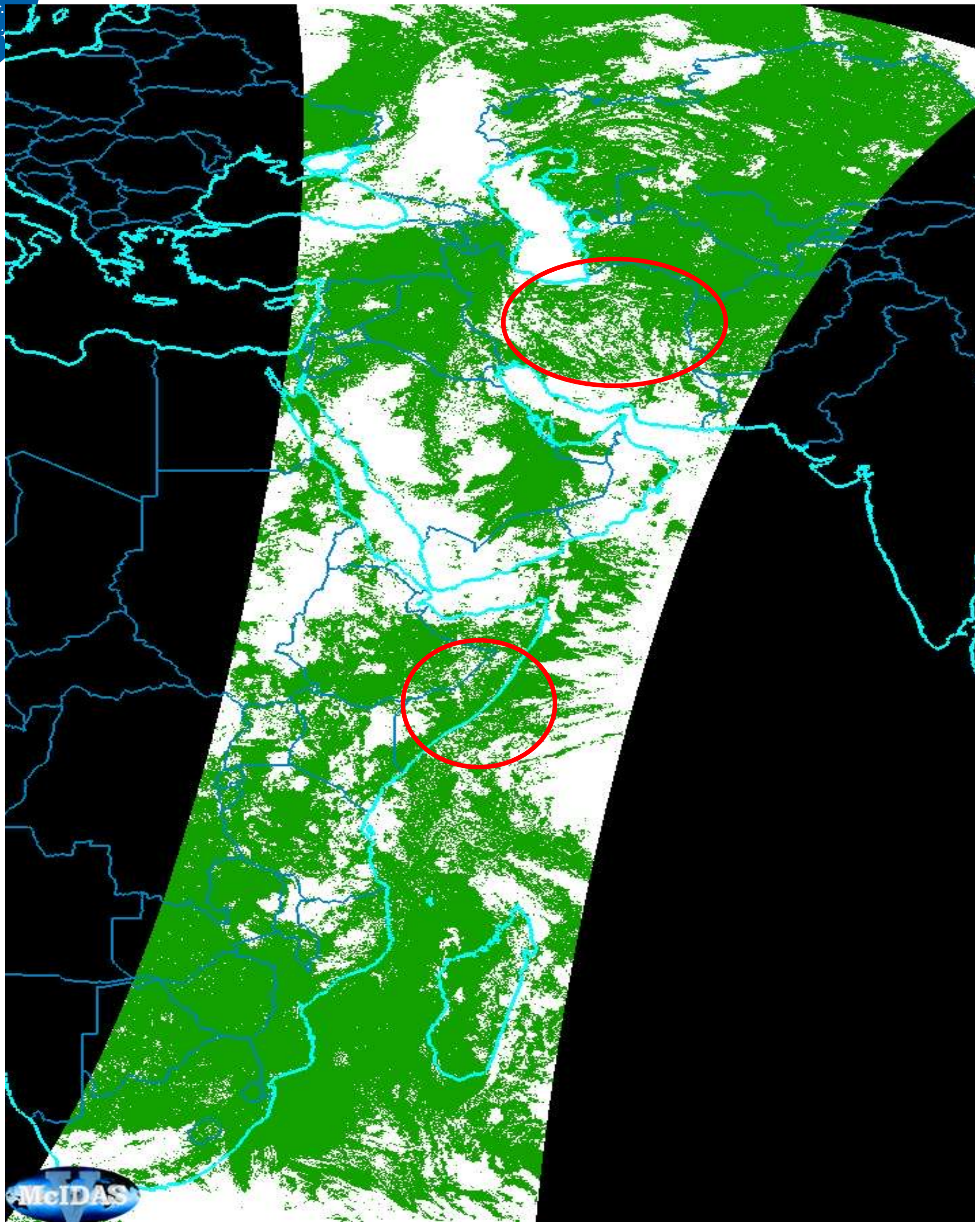
Nighttime Desert :

Ed1A overdetecting clouds over land areas relative to MODIS
Ed1B cloud mask adjusted to agree better with MODIS

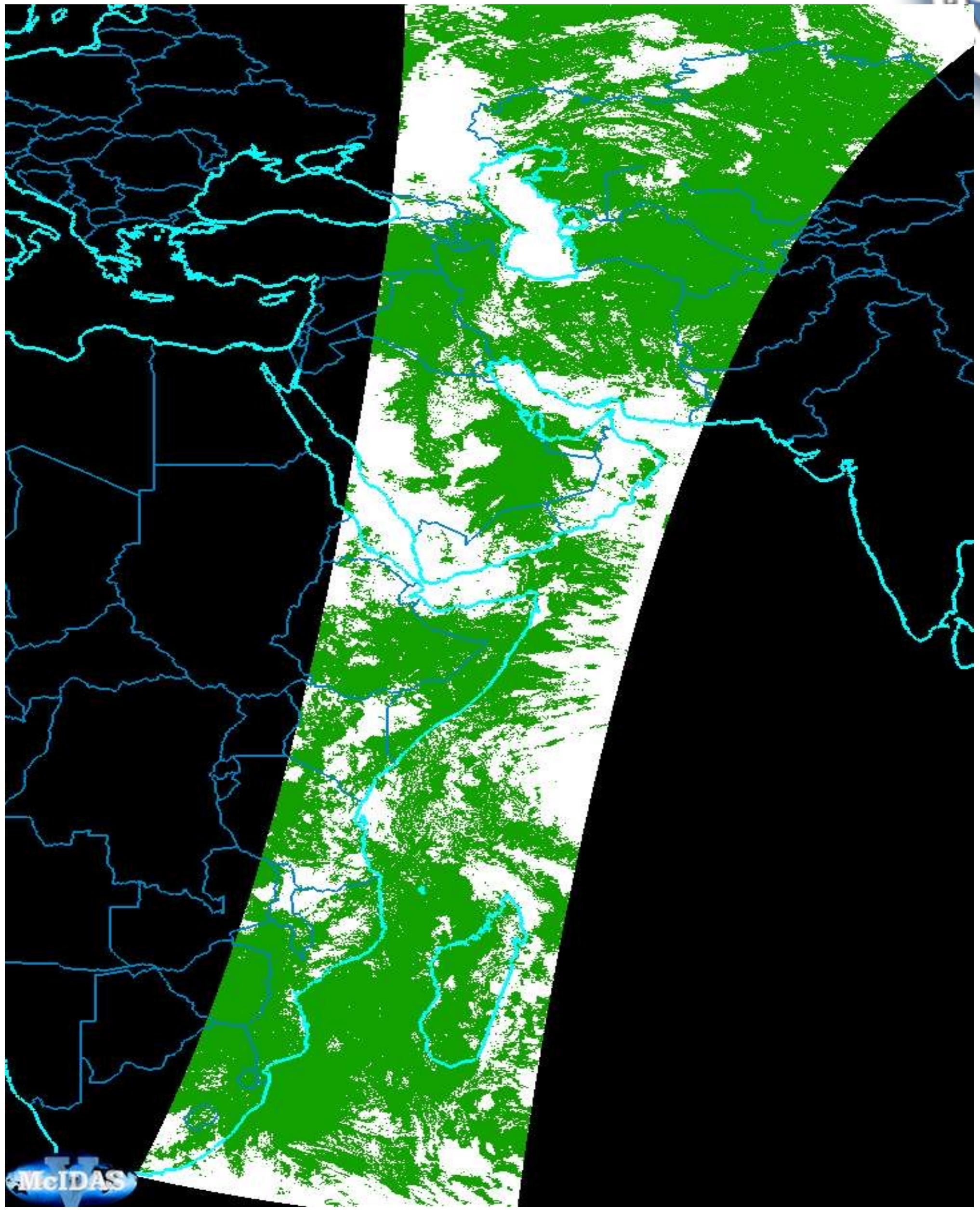




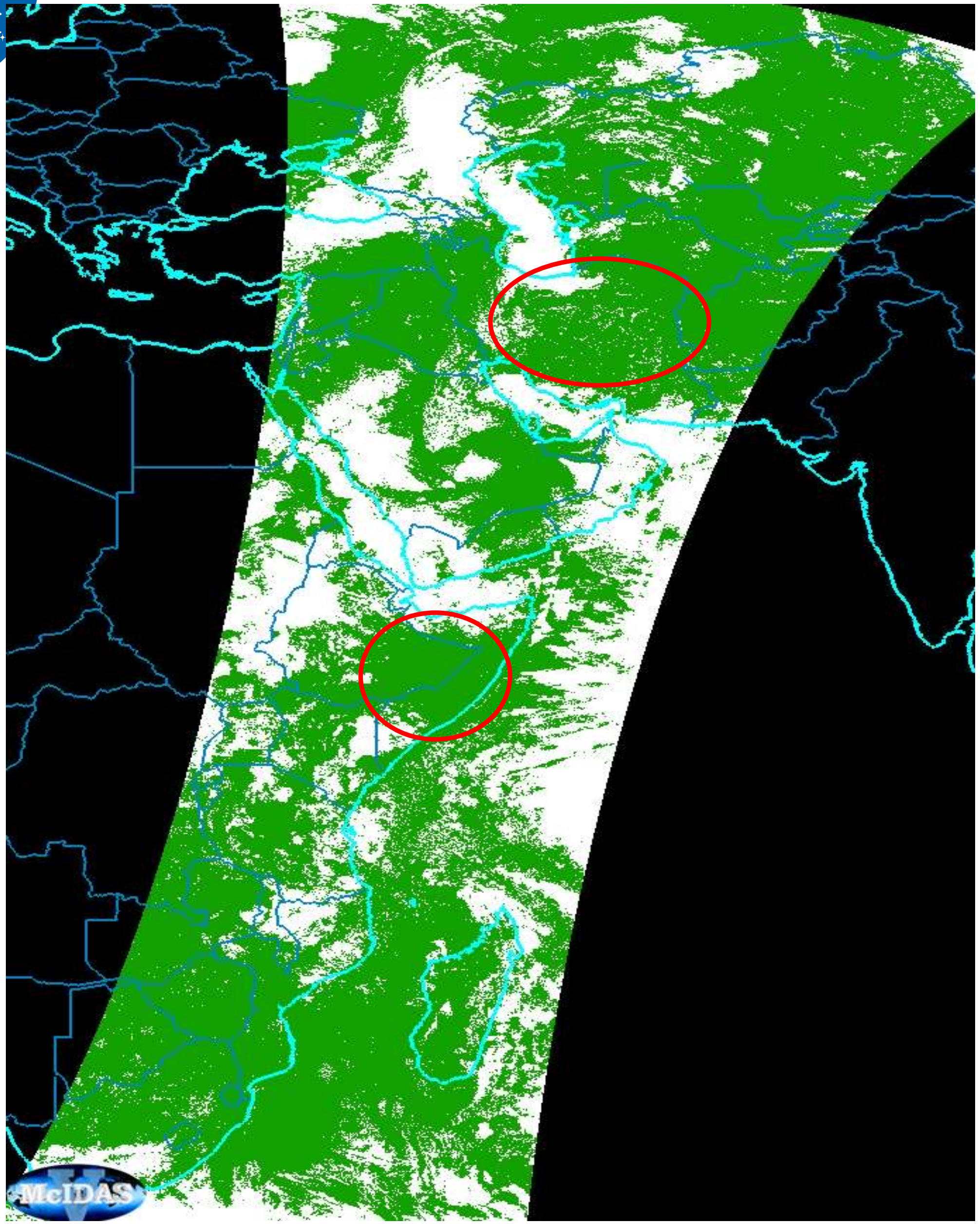
N20 VIIRS
Ed1A mask



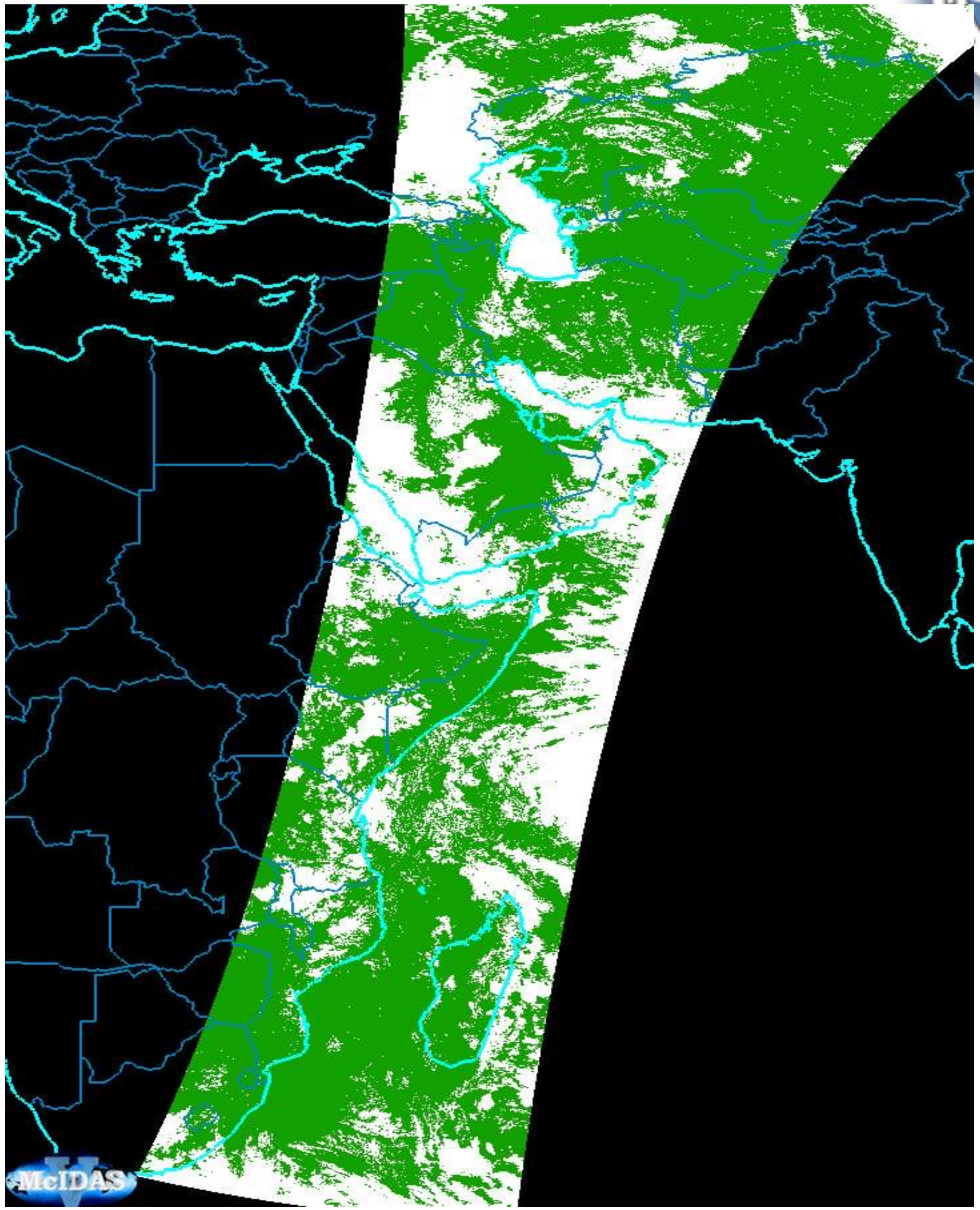
Aqua MODIS
Ed4 mask



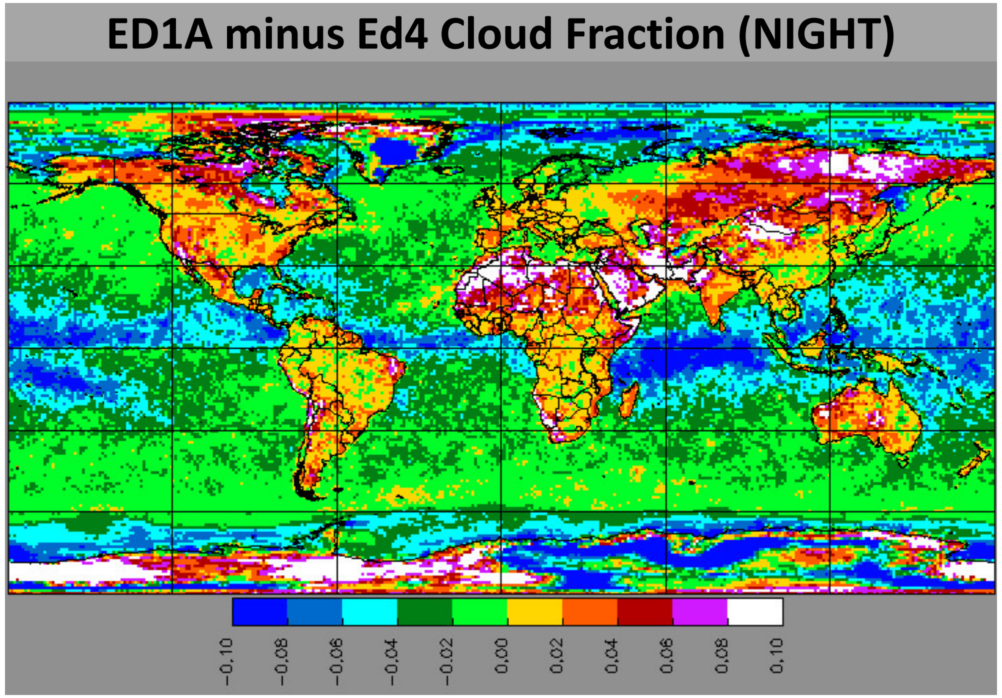
N20 VIIRS
Ed1B mask

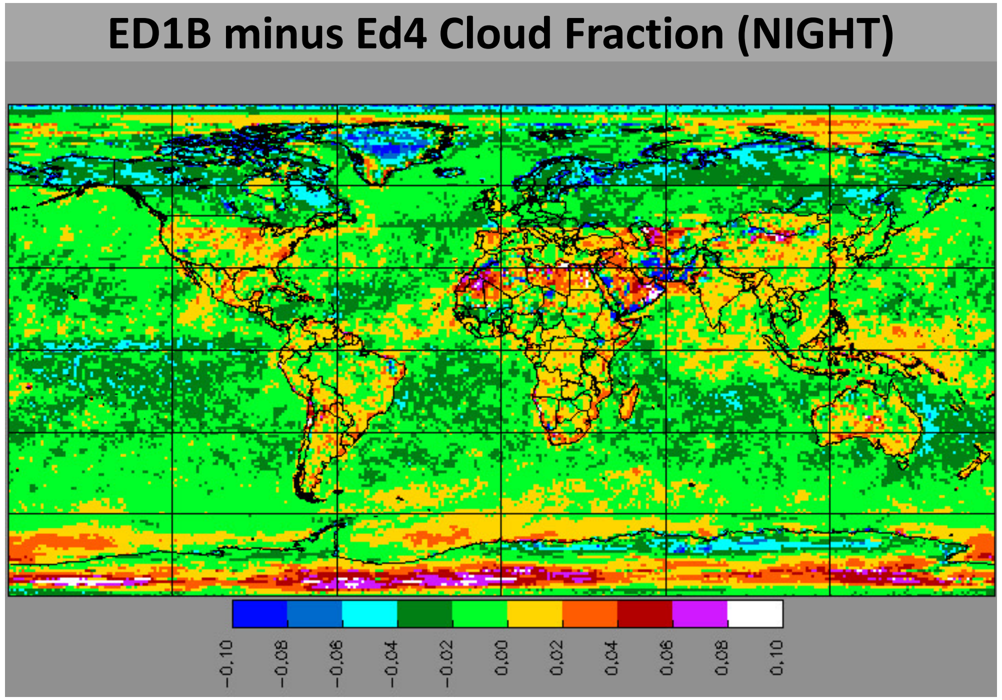


Aqua MODIS
Ed4 mask



VIIRS Comparisons with MODIS Ed4 Cloud Fraction Difference Nighttime, 2018





N20 Ed1A has

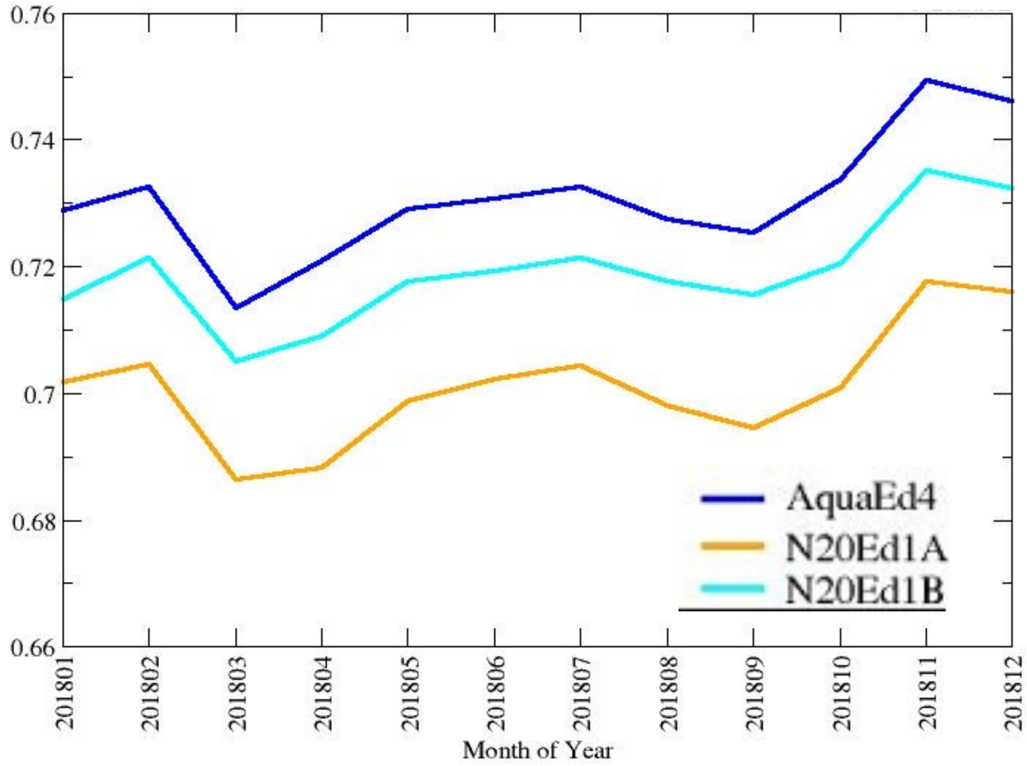
- Less tropical ocean clouds (-10% or more)
- More clouds over land (+10% or more)
- Substantial polar differences
  +/- 30% over Antarctica & Greenland

N20 Ed1B in considerably better agreement with MODIS

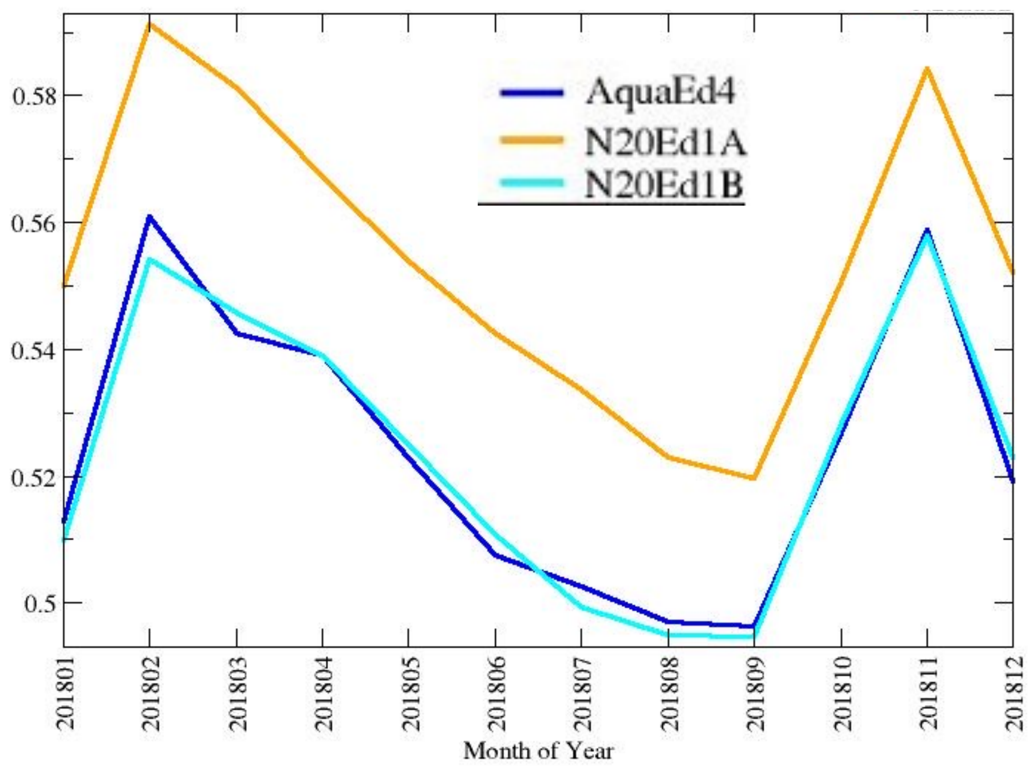
Nighttime Cloud Fraction Comparison

2018 Monthly Mean Timeseries

Non-Polar Ocean



Non-Polar Land



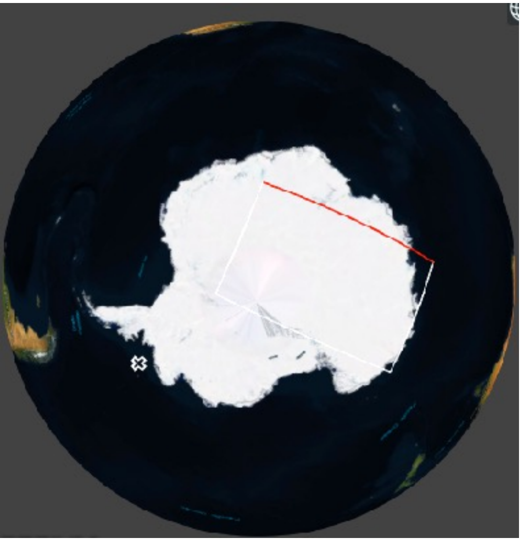
Ed1B non-polar cloud fraction increased ~2%
In better agreement with MODIS Ed4

Ed1B non-polar cloud fraction decreased ~4%
In great agreement with MODIS Ed4

2. Reduce polar daytime and nighttime cloud fraction differences

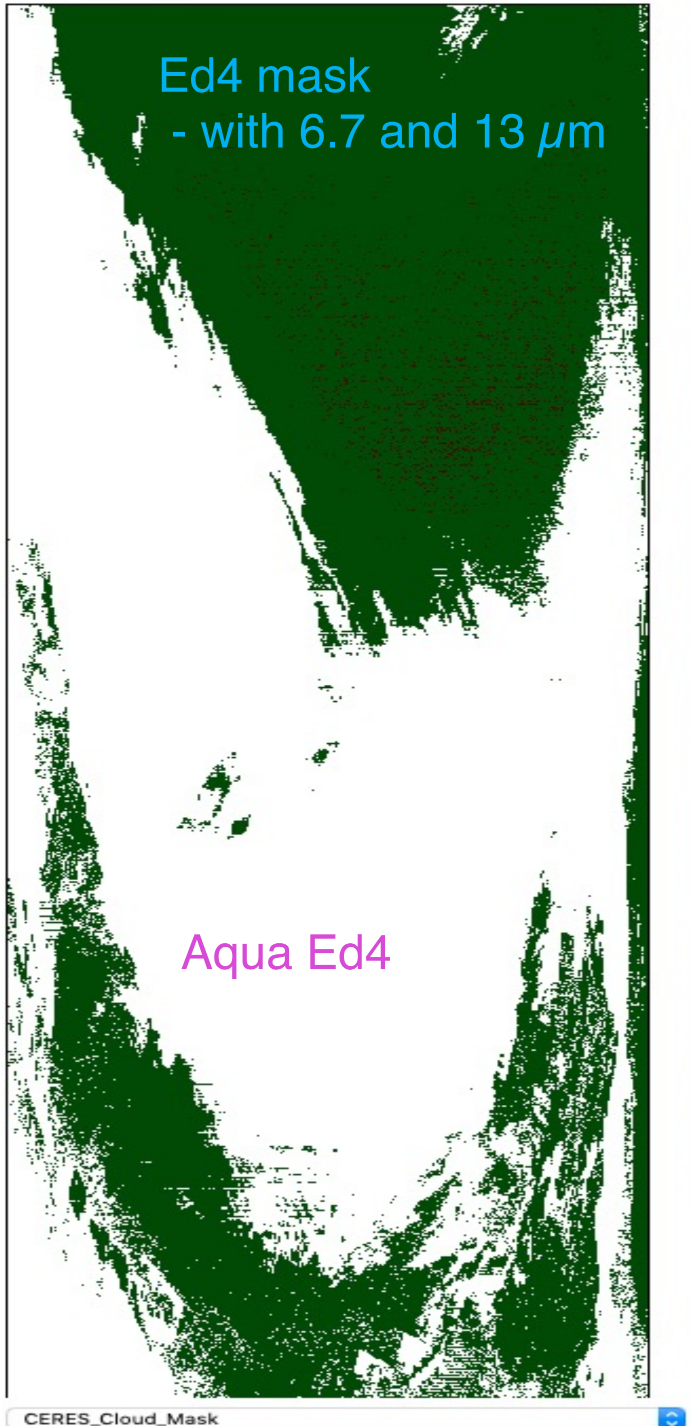
- Ingested a CrIS/VIIRS fusion data product that provides a WV and CO2 channel for VIIRS (see Bryan Baum talk on Thursday)

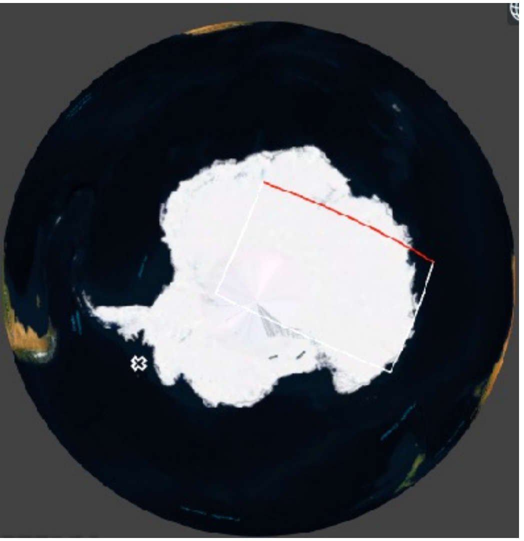
- Modified the polar cloud mask algorithm to use CO2 and WV channels as in Ed4



Aqua 2019 07 15 09UTC

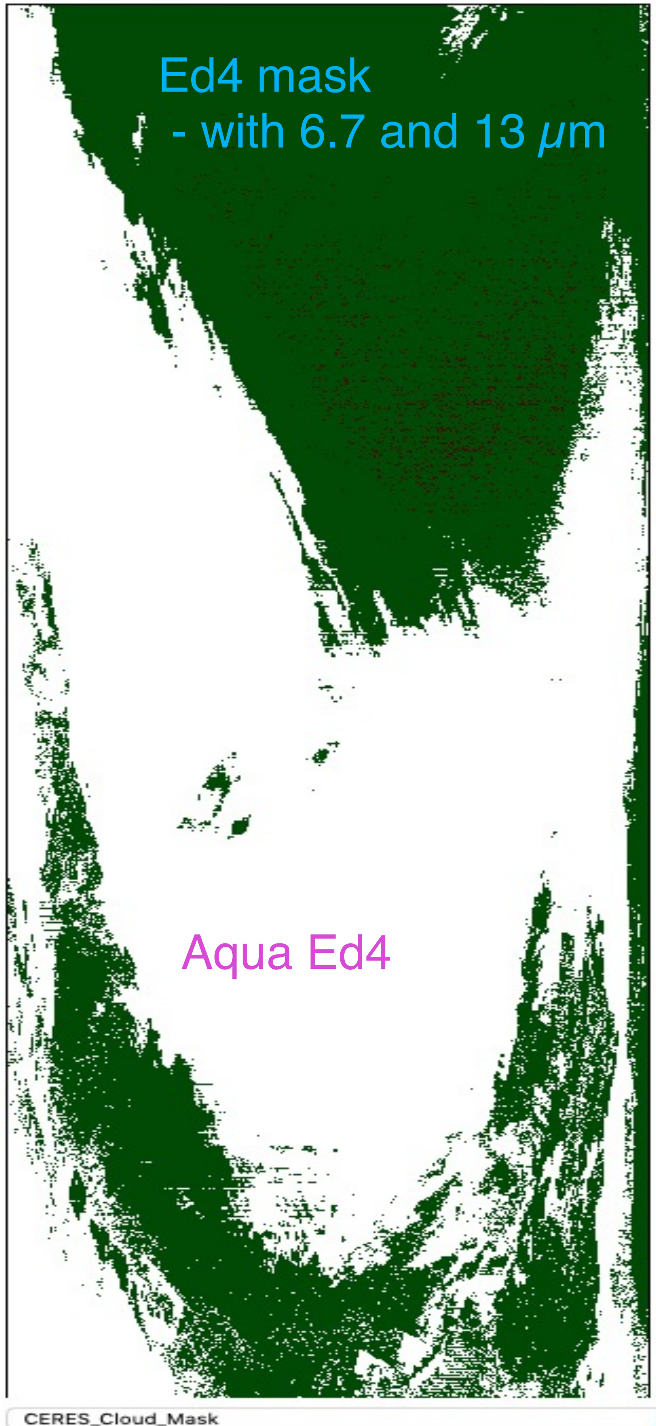
Polar Night

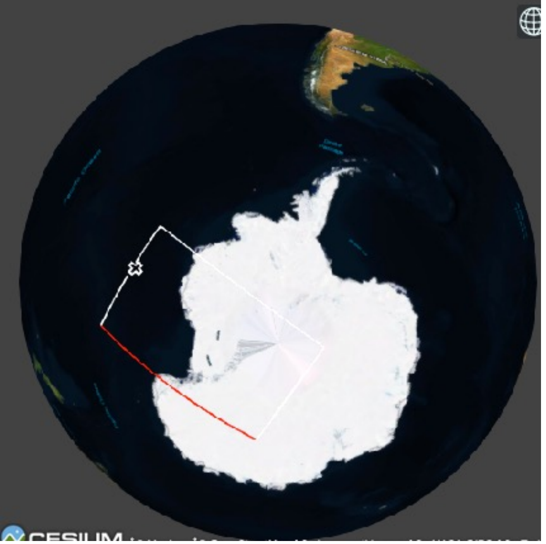




Aqua 2019 07 15 09UTC

Polar Night

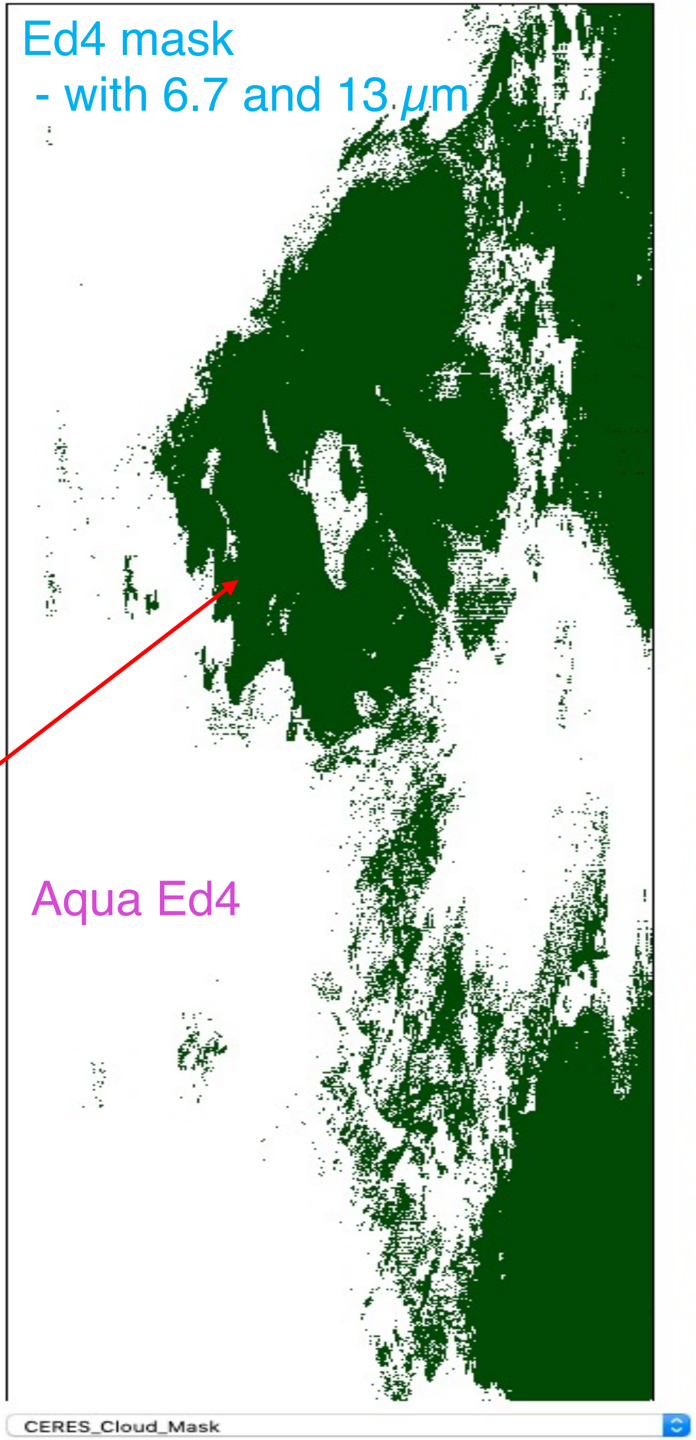


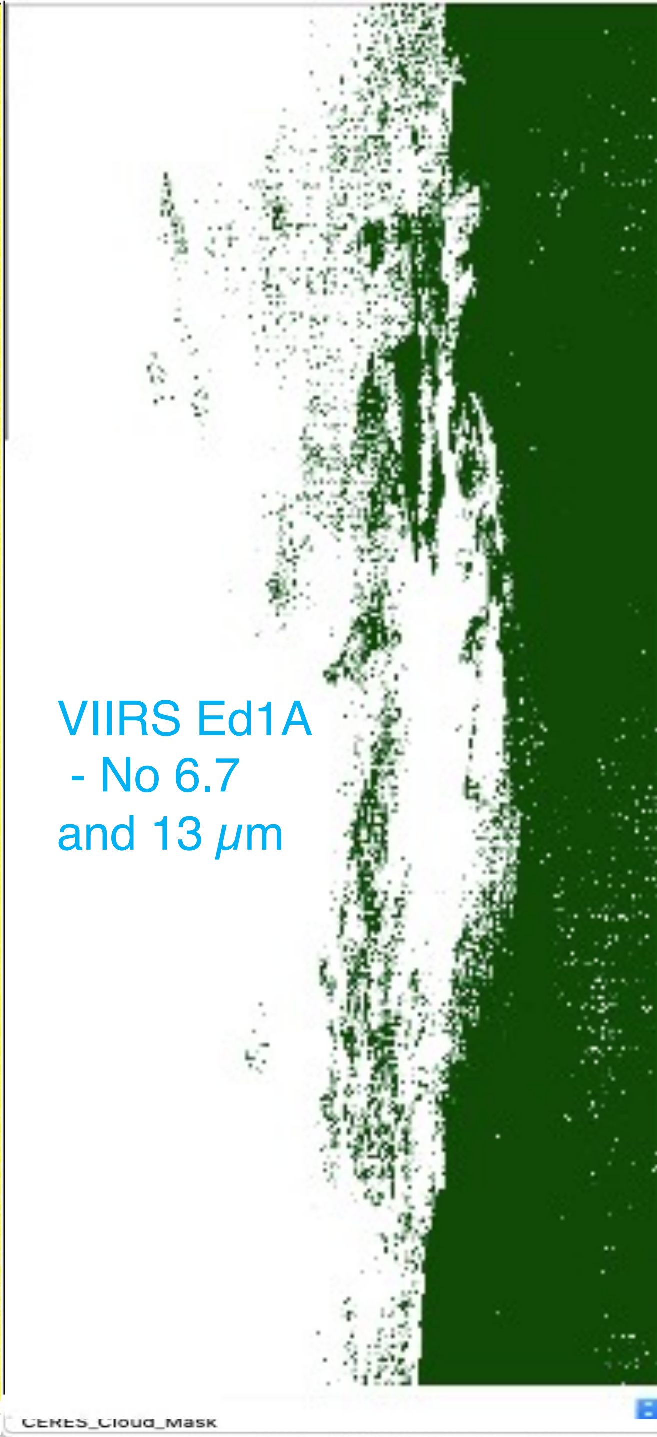


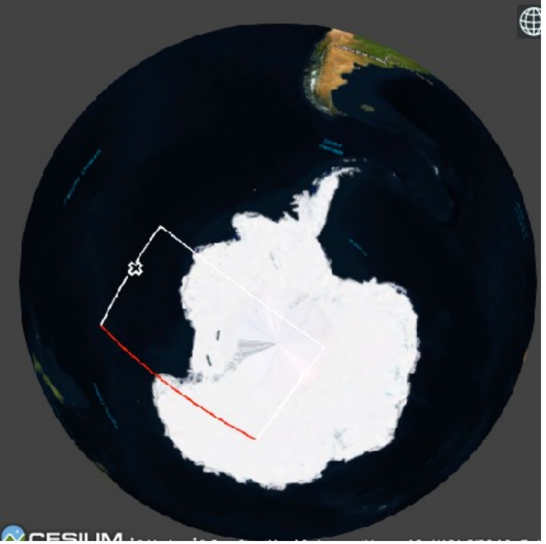
Aqua 2019 07 15 04UTC

Polar Night

Clear Restore
With 6.7 & 13.3 μm

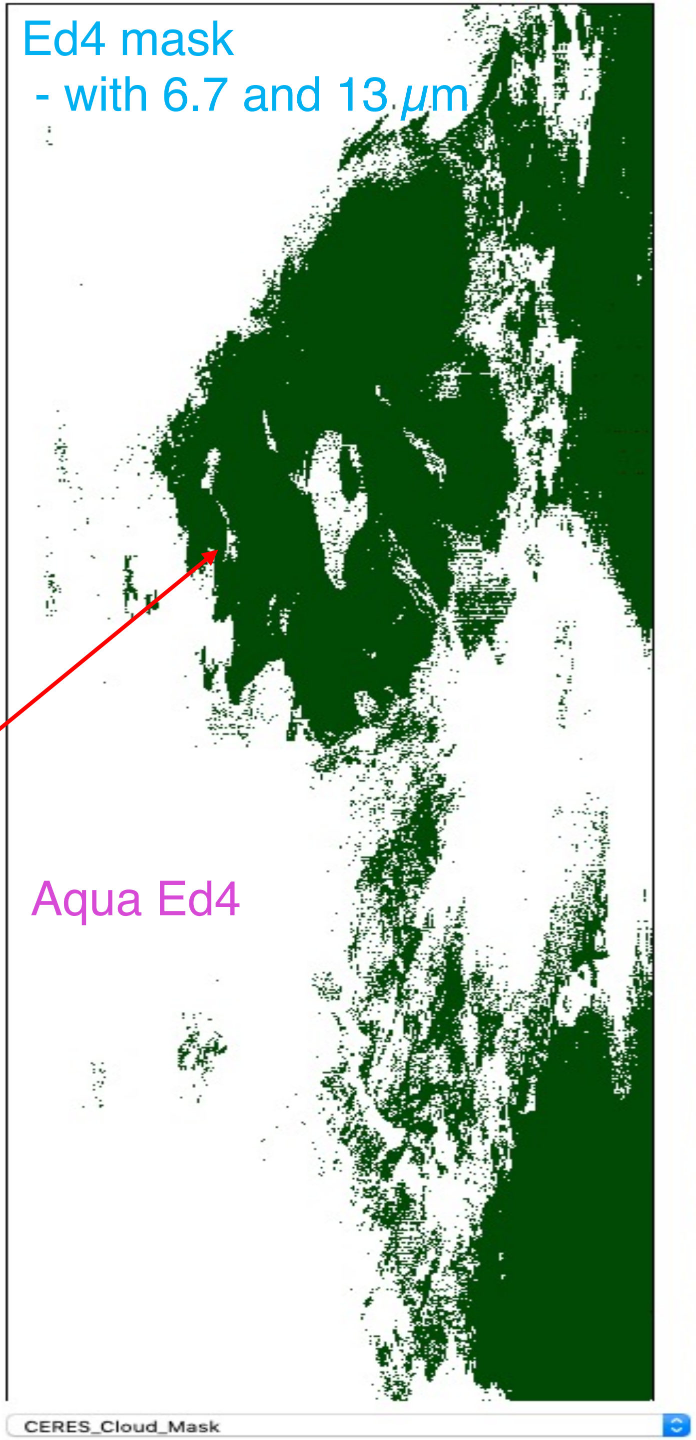


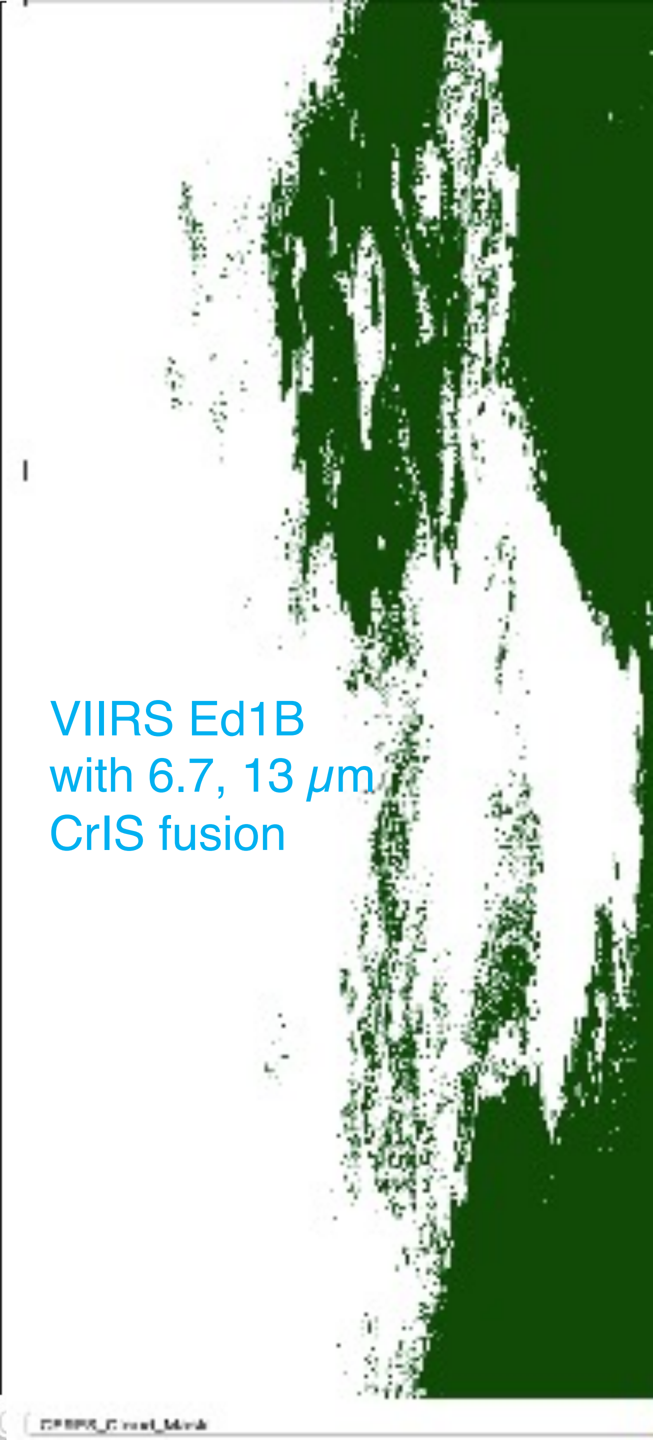




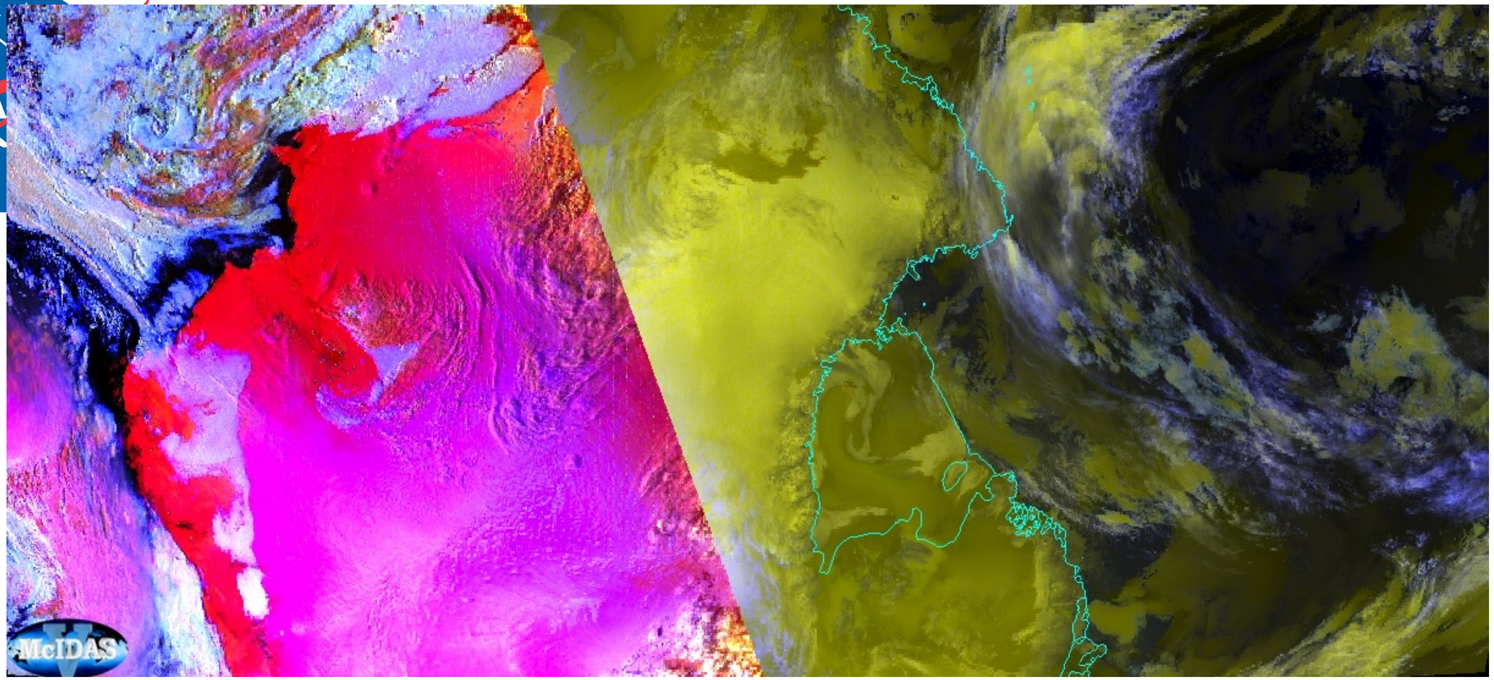
Aqua 2019 07 15 04UTC

Clear Restore
With 6.7 & 13.3 μm

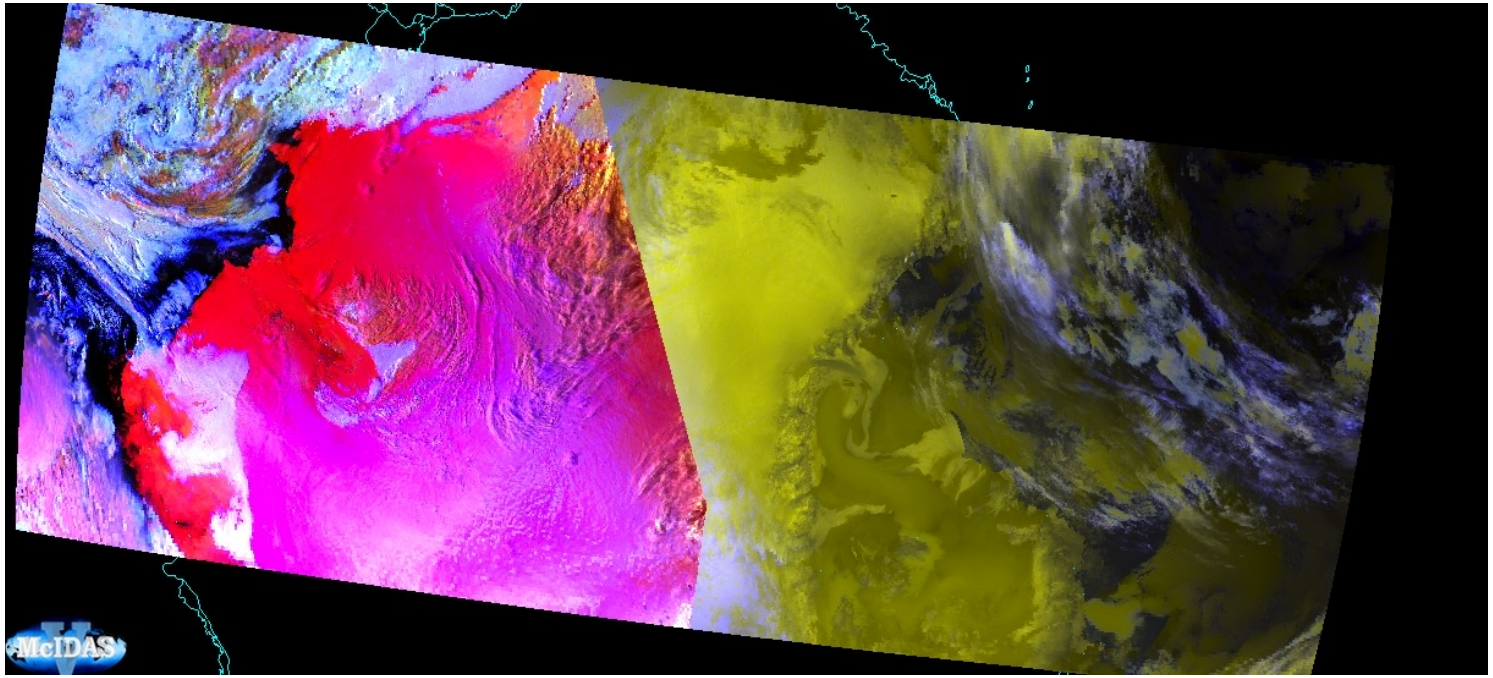




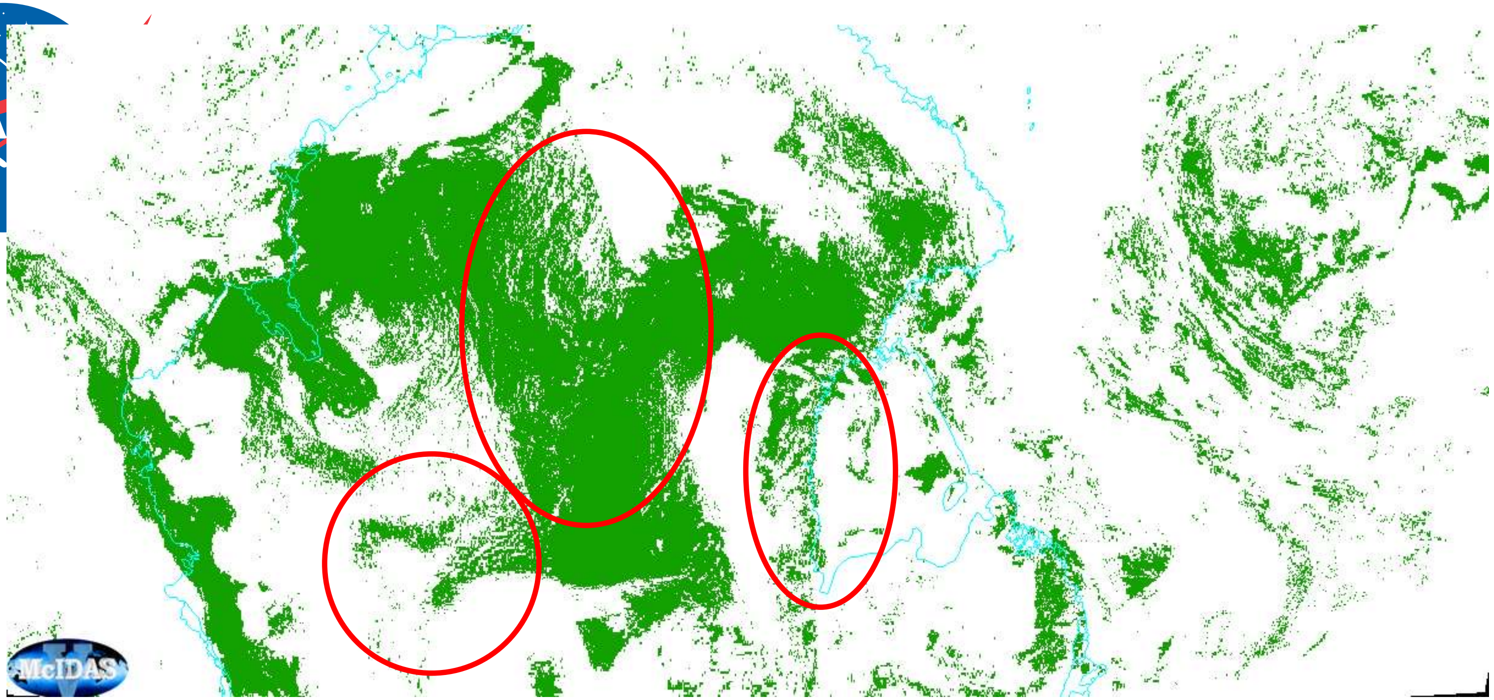
Antarctica day/twi/night:



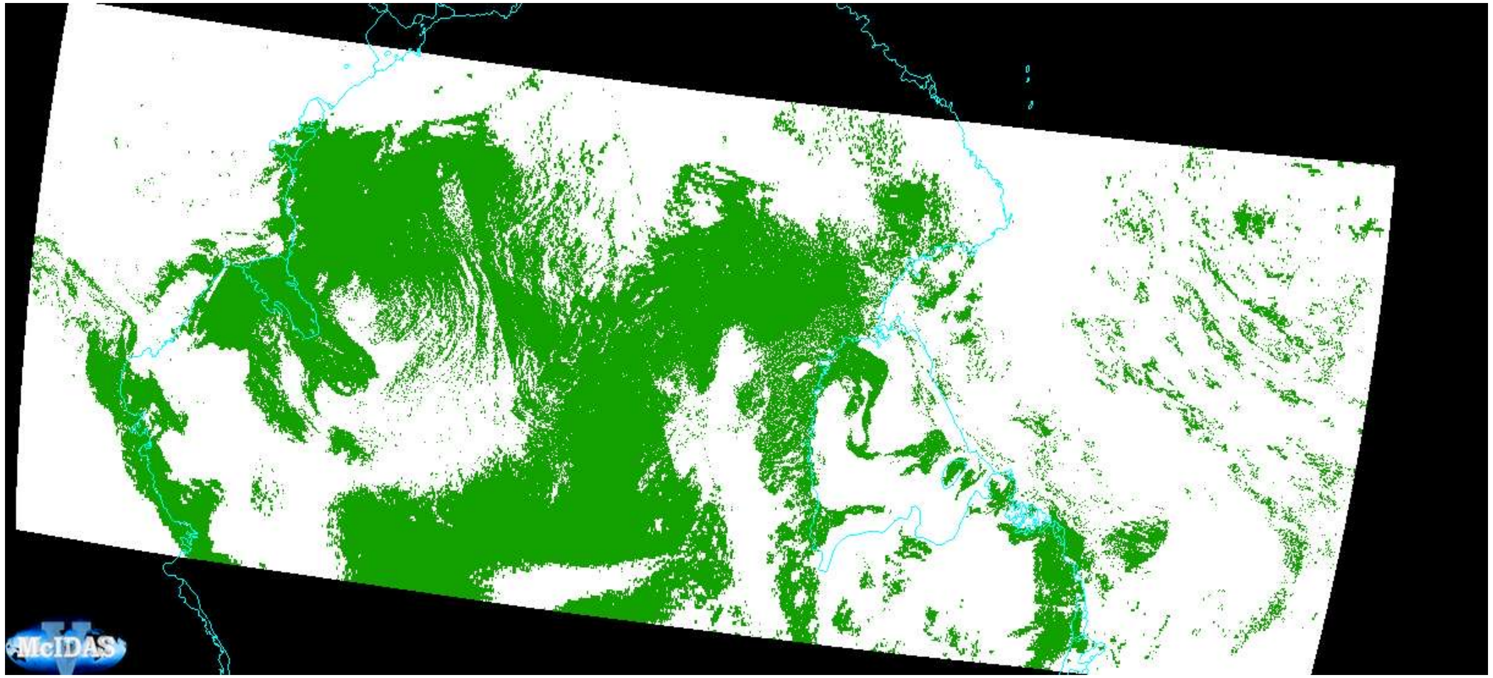
NOAA20 VIIRS
March 13, 2019, UTC10



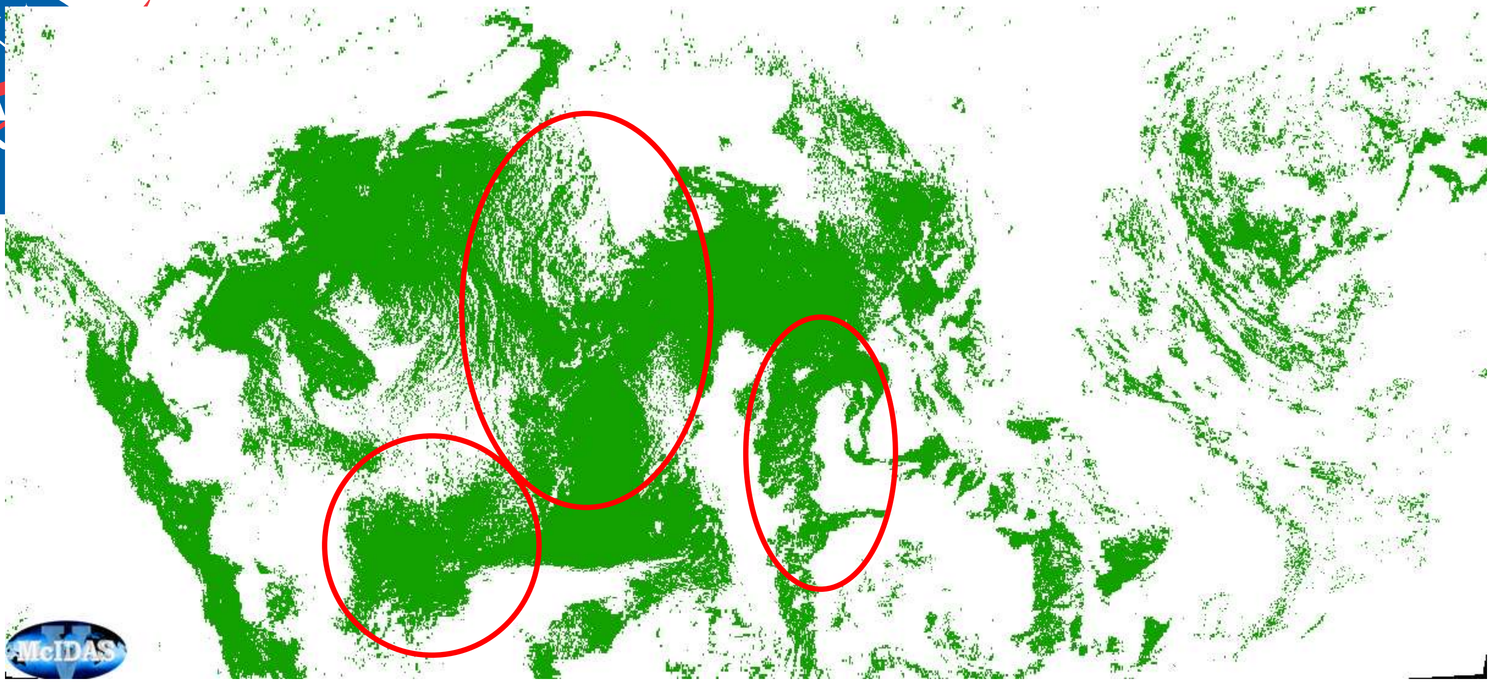
Aqua MODIS
March 13, 2019, UTC10



NOAA20 VIIRS Ed1A

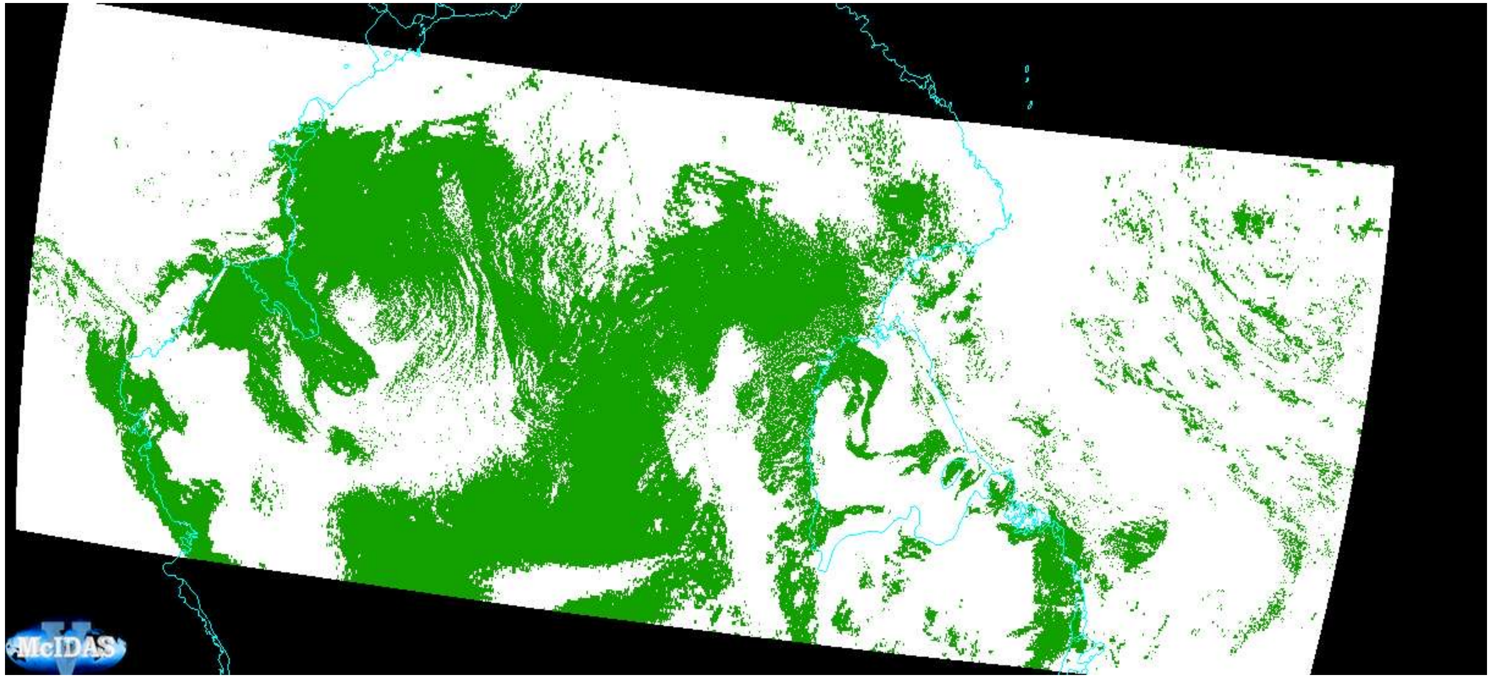


Aqua MODIS Ed4



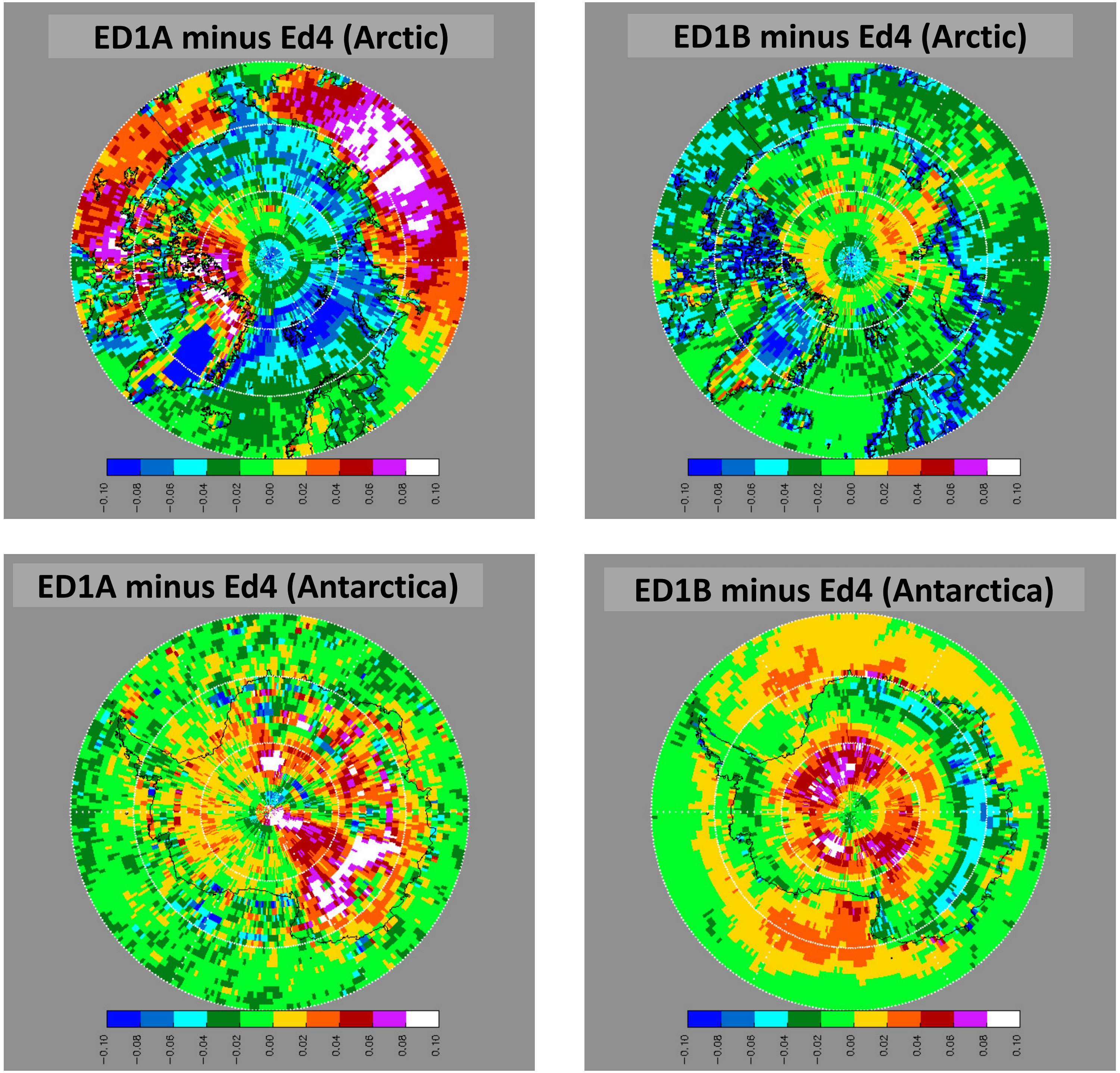
NOAA20 VIIRS Ed1B

Ed1B much closer to Ed4



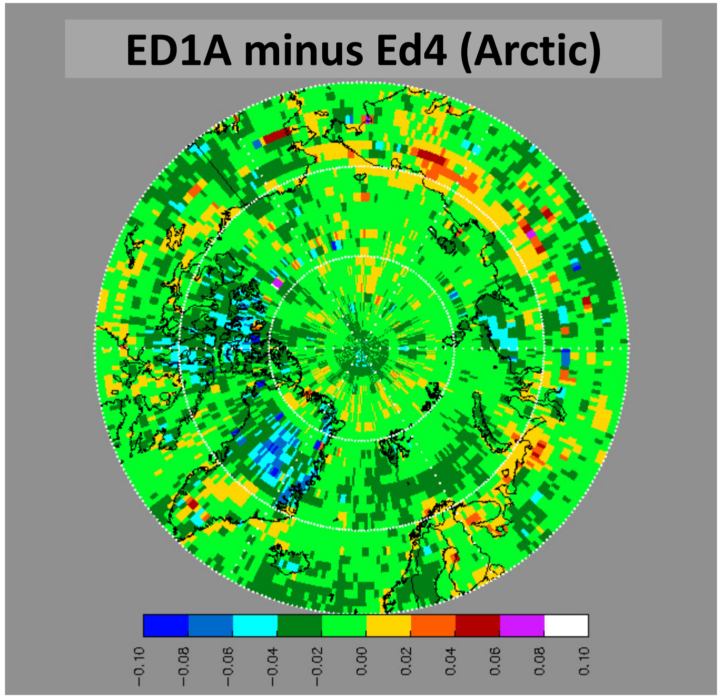
Aqua MODIS Ed4

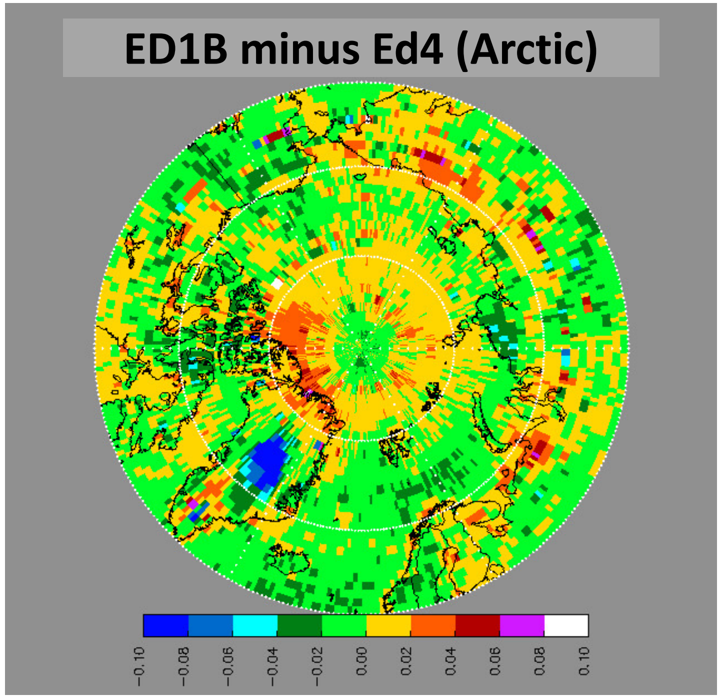
Cloud Fraction
Nighttime Polar, 2018



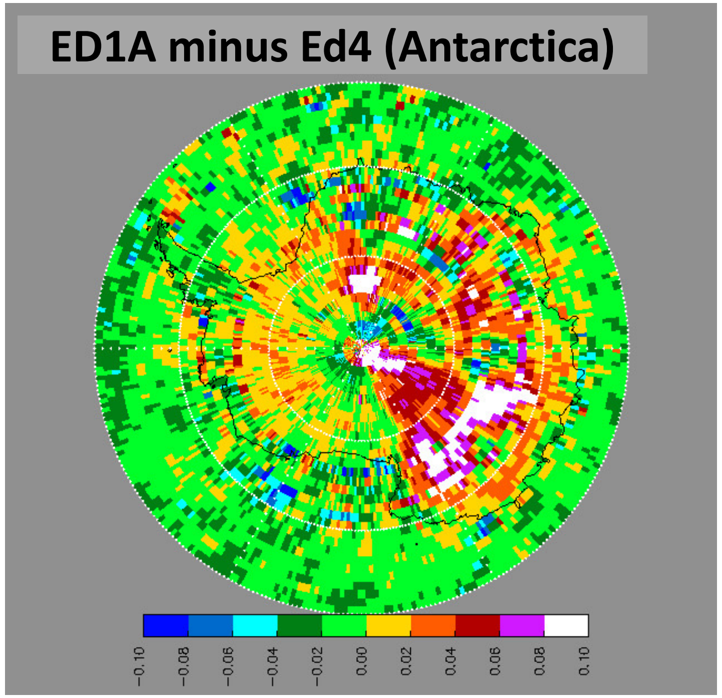
- Substantial polar differences found in Ed1A compared to MODIS (+/- 30% in some months over land areas)
- Generally, much better agreement in Ed1B, although still some significant regional differences
- Struggling with 3.7 µm channel on VIIRS which is much less sensitive and noisier than MODIS at cold temperatures

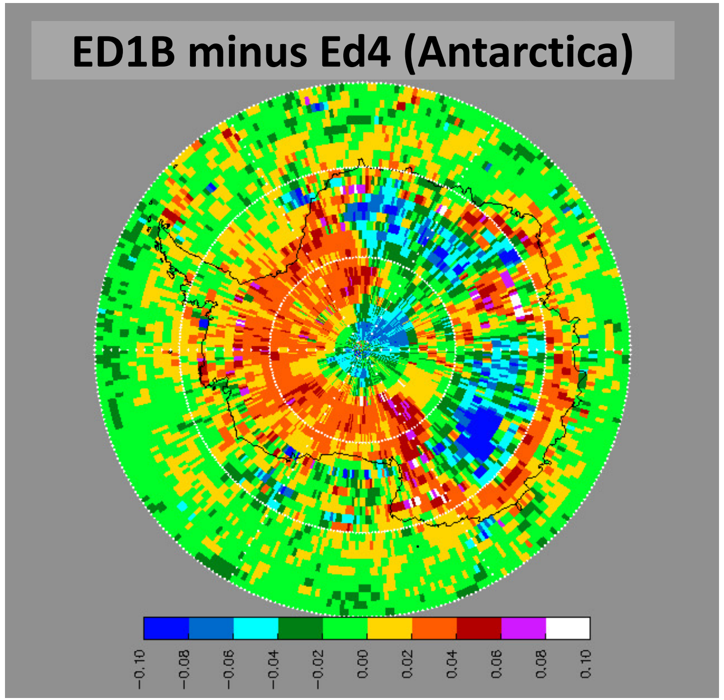
Cloud Fraction
Daytime Polar, 2018





Less bias but greater rms differences
In Ed1b over north polar regions





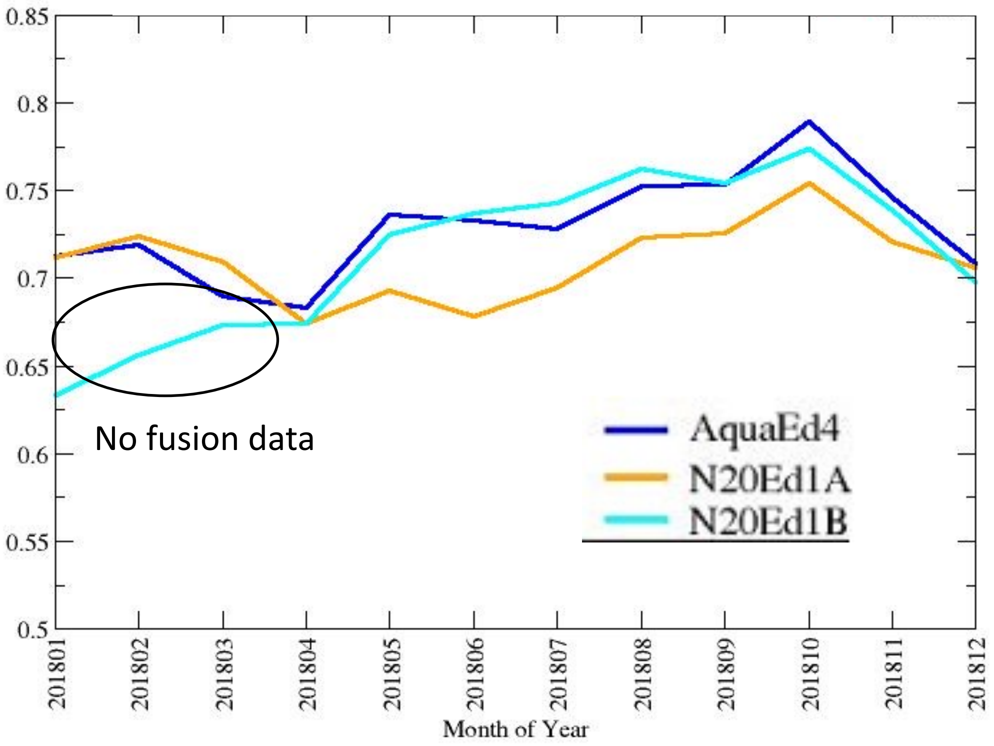
Some improvement over Plateau
but worse agreement over west
Antarctica in Ed1B daytime

Daytime polar mask did not get much attention

Nighttime Cloud Fraction Comparison

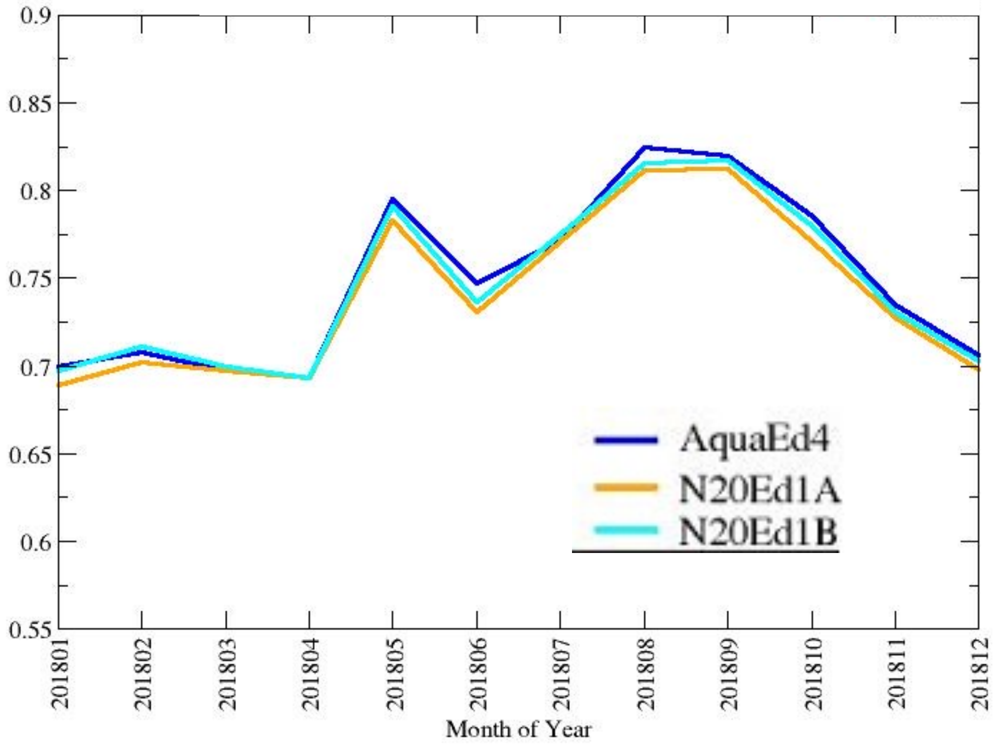
2018 Monthly Mean Timeseries

Nighttime Polar



- Ed1B polar cloud fraction increased ~5%
- In better agreement with MODIS Ed4
- Poor Ed1B agreement when no fusion data

Daytime Polar

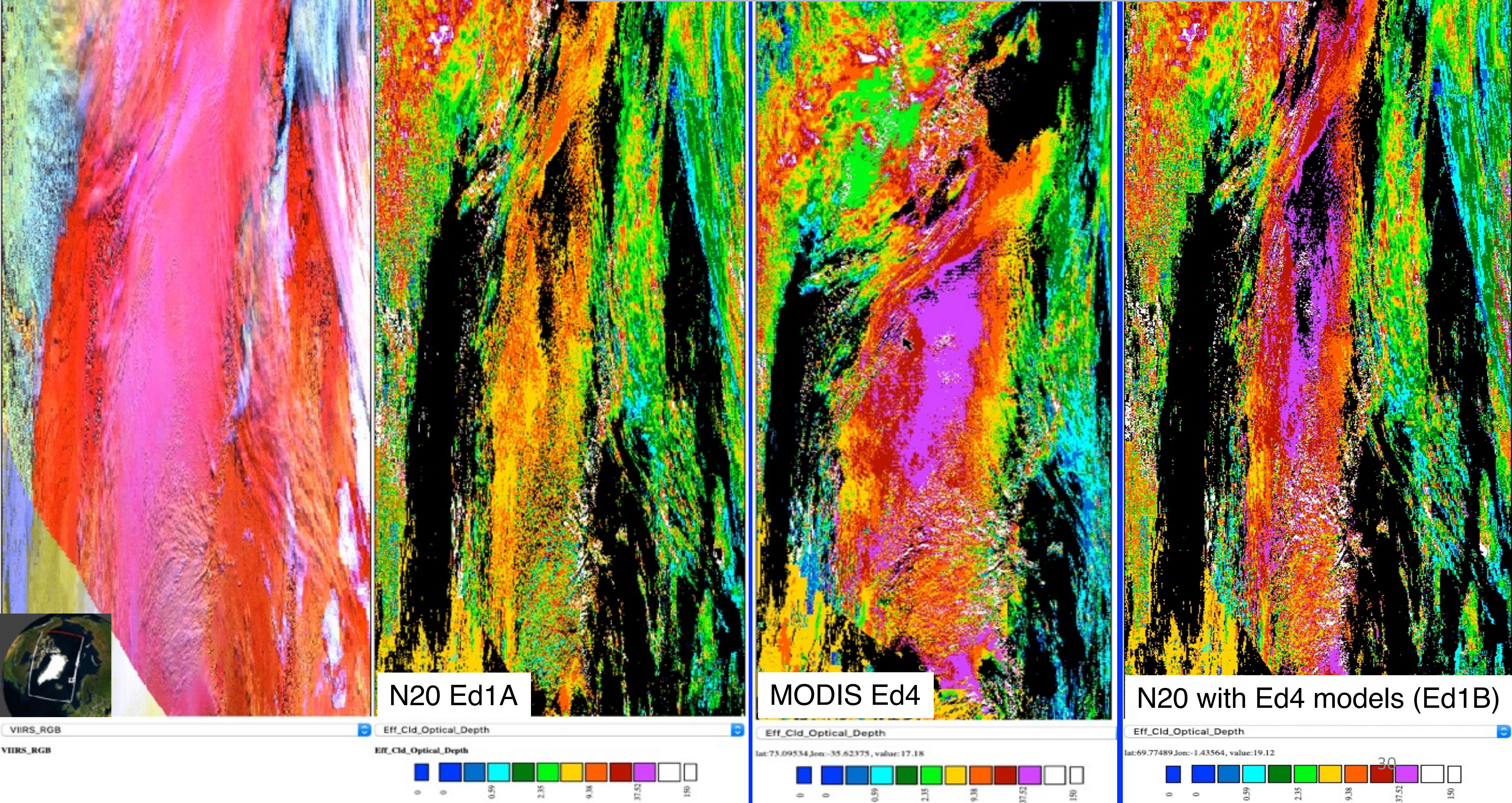


- All versions agree well overall
- Ed1B in slightly better agreement with MODIS
- Satellites track each other better in daytime

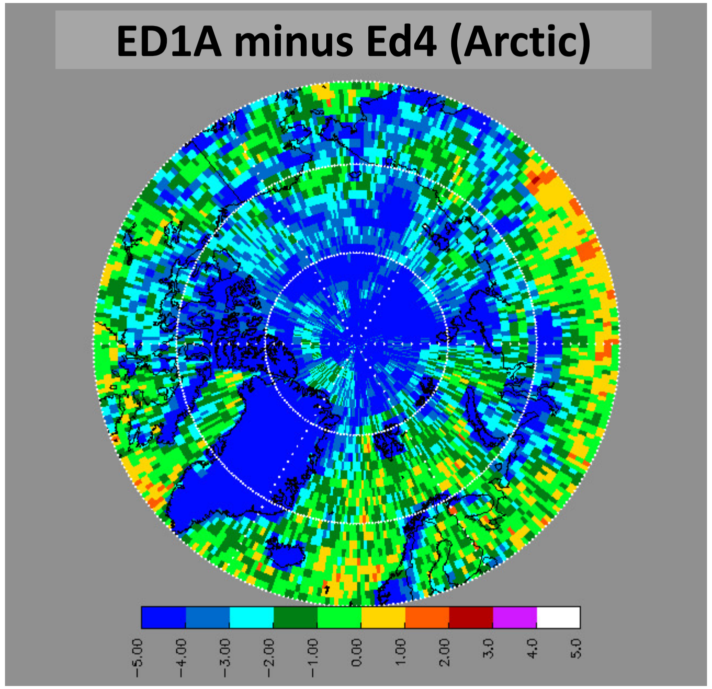
3. Obtain better agreement in cloud optical properties over polar regions

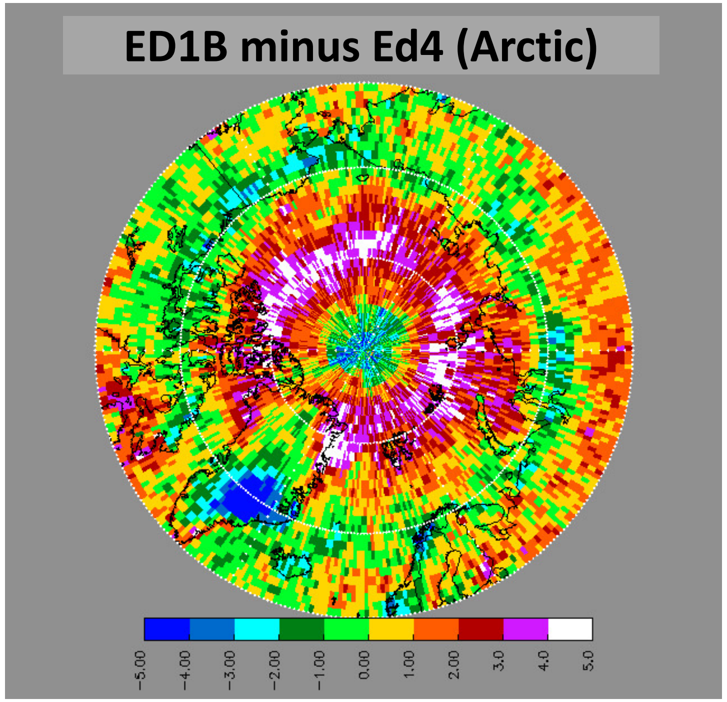
Replaced the VIIRS 1.24 um and 3.7 um reflectance cloud models and parameterizations with those from Ed4 (Ed4 models have an interpolation bug and other inconsistencies)

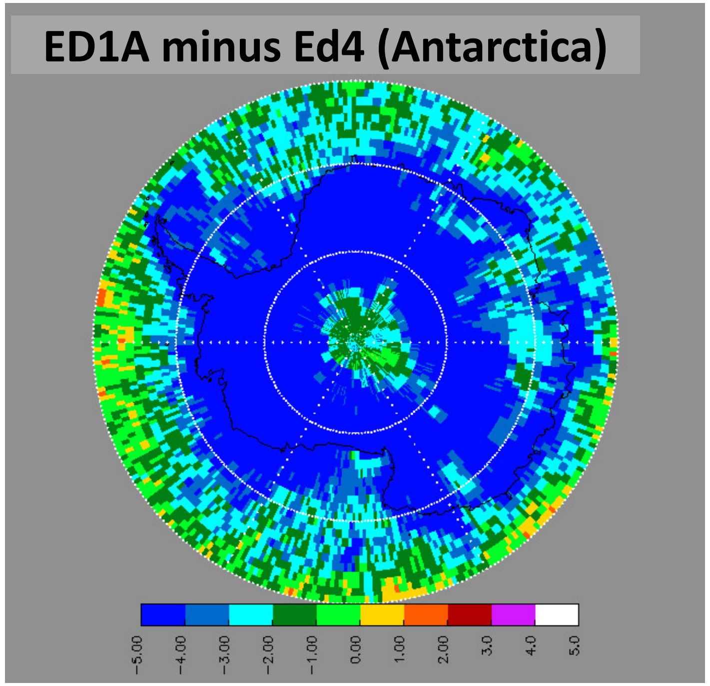
Daytime Cloud Optical Thickness Comparison over Greenland

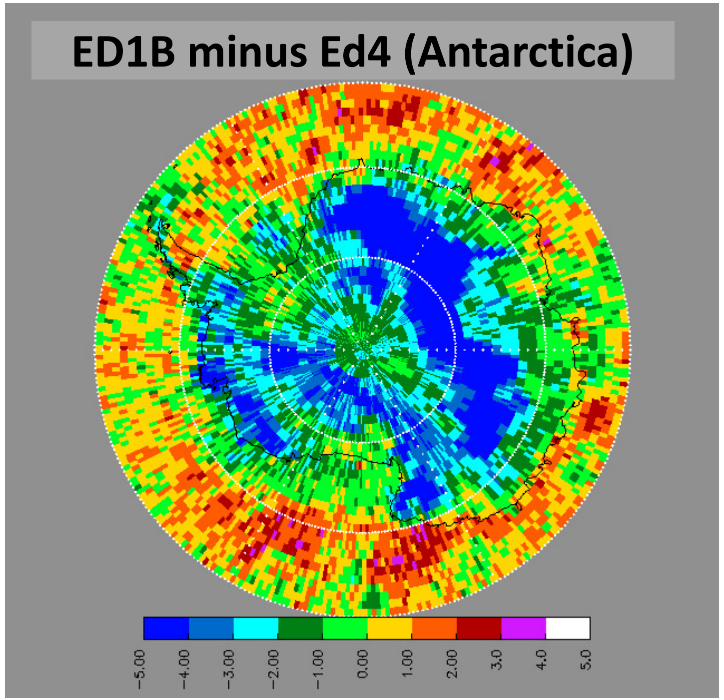


Ice Cloud Optical Depth Daytime Polar, 2018







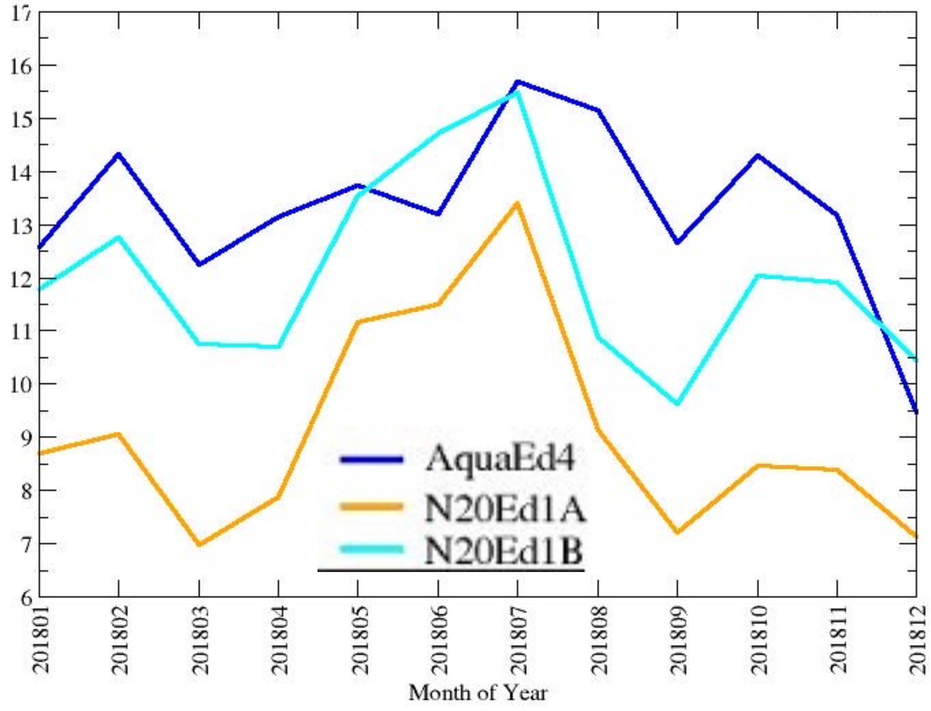


Ed1A optical depth is much lower (more accurate) than Ed4.

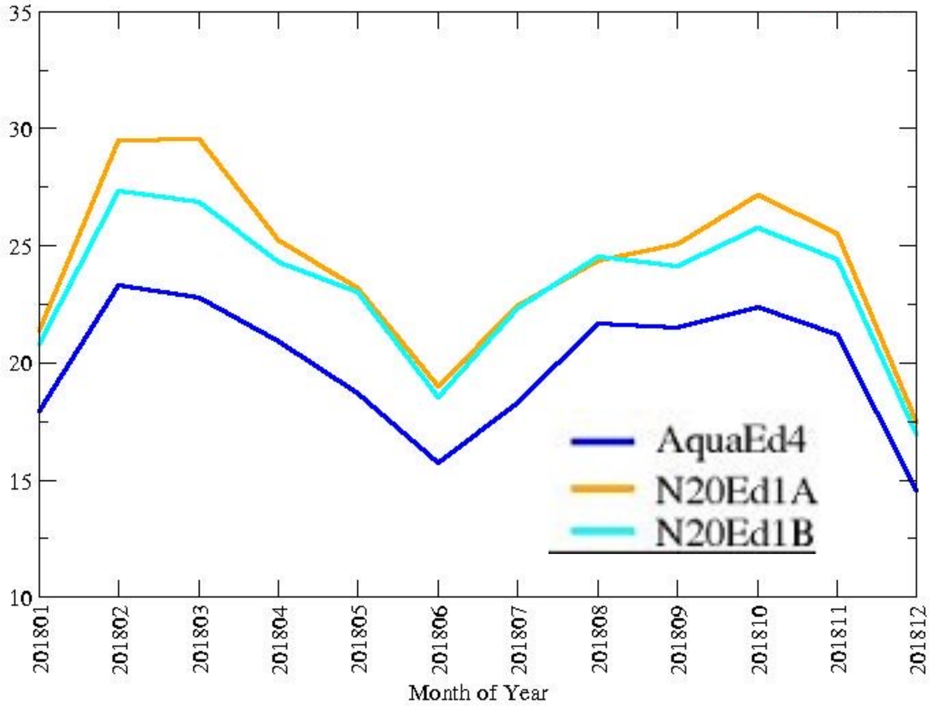
Implementation of the Ed4 'buggy' models in Ed1B improves VIIRS consistency with MODIS Ed4 over both polar regions

Daytime Cloud Optical Depth
2018 Monthly Mean Timeseries

Daytime Polar Ice Clouds



Daytime Polar Water Clouds



Ed1B polar cloud optical depths in better agreement with MODIS Ed4

Not much improvement for water clouds (bug was in the ice cloud models)

Progress Towards Edition 5 Clouds

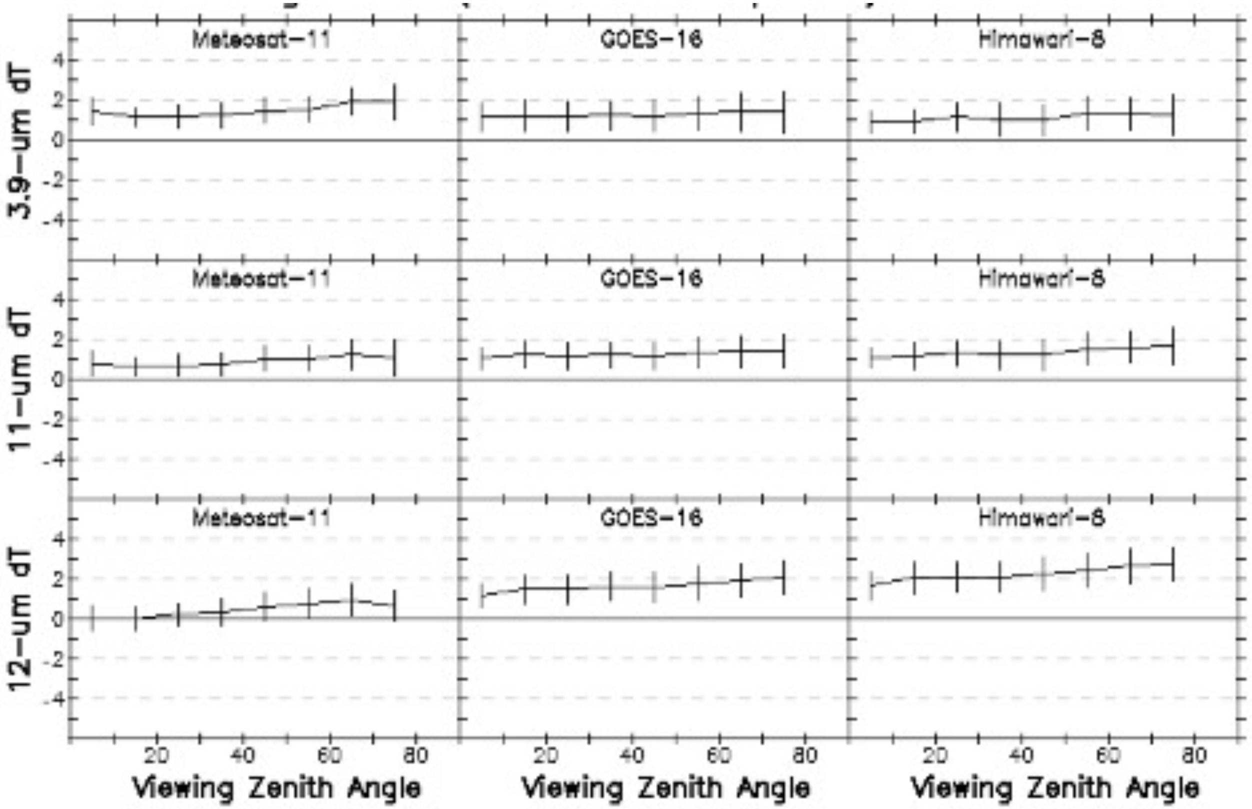
1. Improved atmospheric corrections using correlated k-distribution method
   - Increased number of levels from 19 to 58
   - Accounting for satellite specific SRF's across all platforms
   - Improved segmentation across spectral bands for various gases
   - Continuum absorption update for SEVIRI 3.9 µm band
2. Exploring machine learning to address challenging cloud retrieval problems, e.g.
   - Poor day/night consistency in cloud properties due to IR blackbody limit at night
   - Challenges in the solar terminator
   - Challenges detecting polar clouds at night

CERES GEO Atmospheric Correction Update

NIGHTTIME evaluations over Clear-sky Ocean

Ed4 GEO

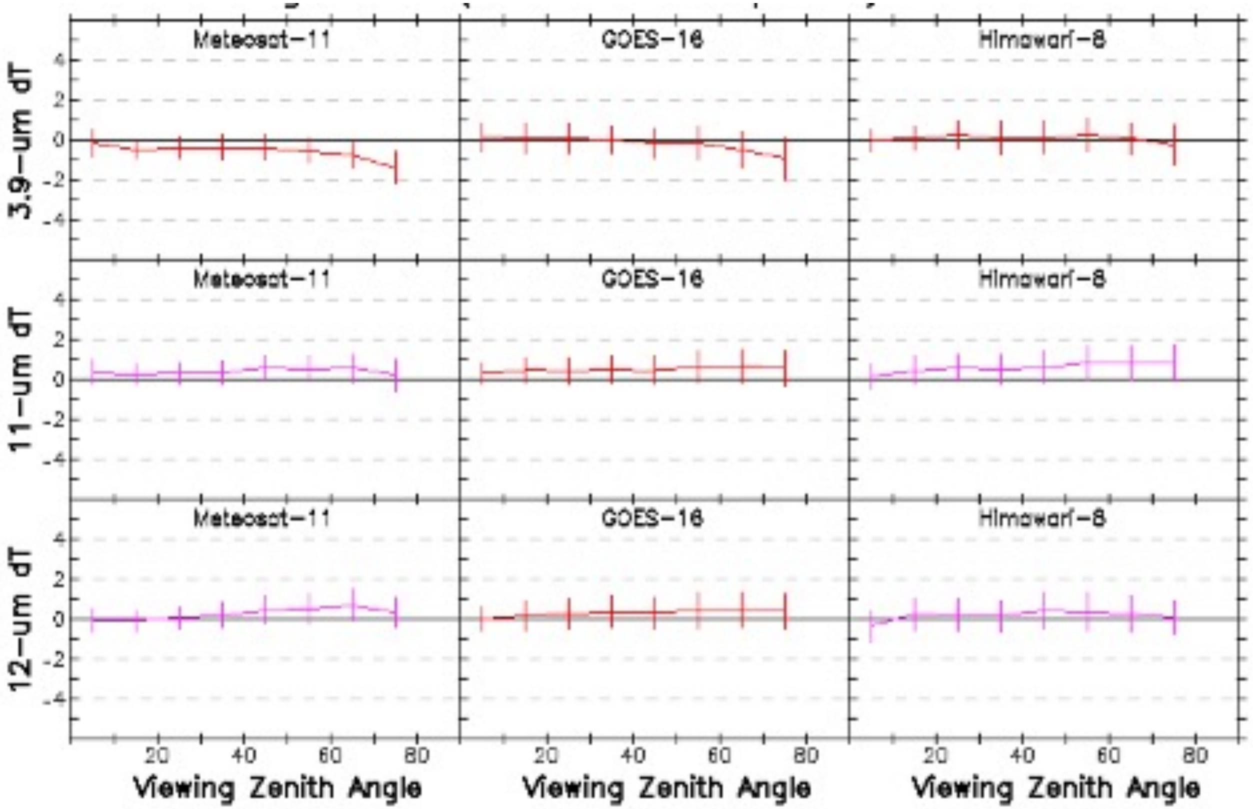
Meteosat-11 GOES-16 Himawari-8



Errors > 1K

Updated for Ed5

Meteosat-11 GOES-16 Himawari-8



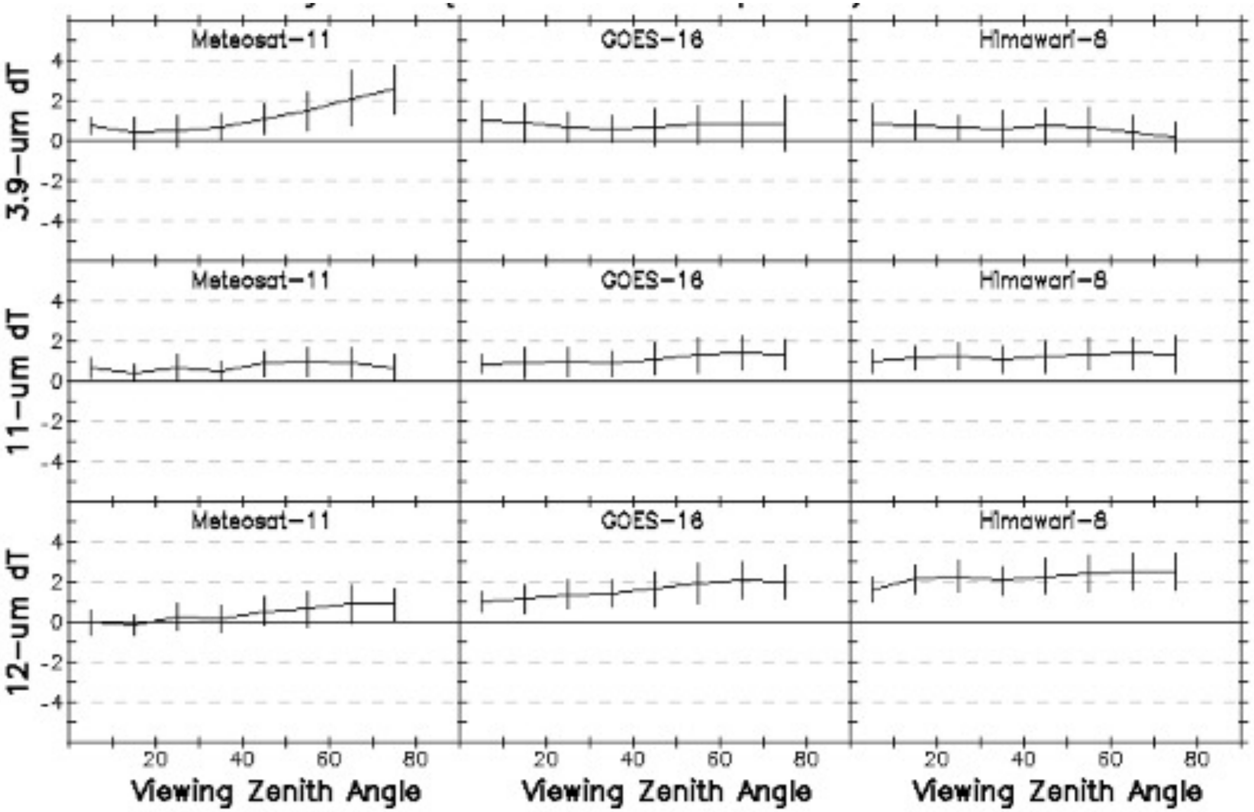
Errors < ~ 0.2 K

CERES GEO Atmospheric Correction Update

DAYTIME evaluations over Clear-sky Ocean

Ed4 GEO

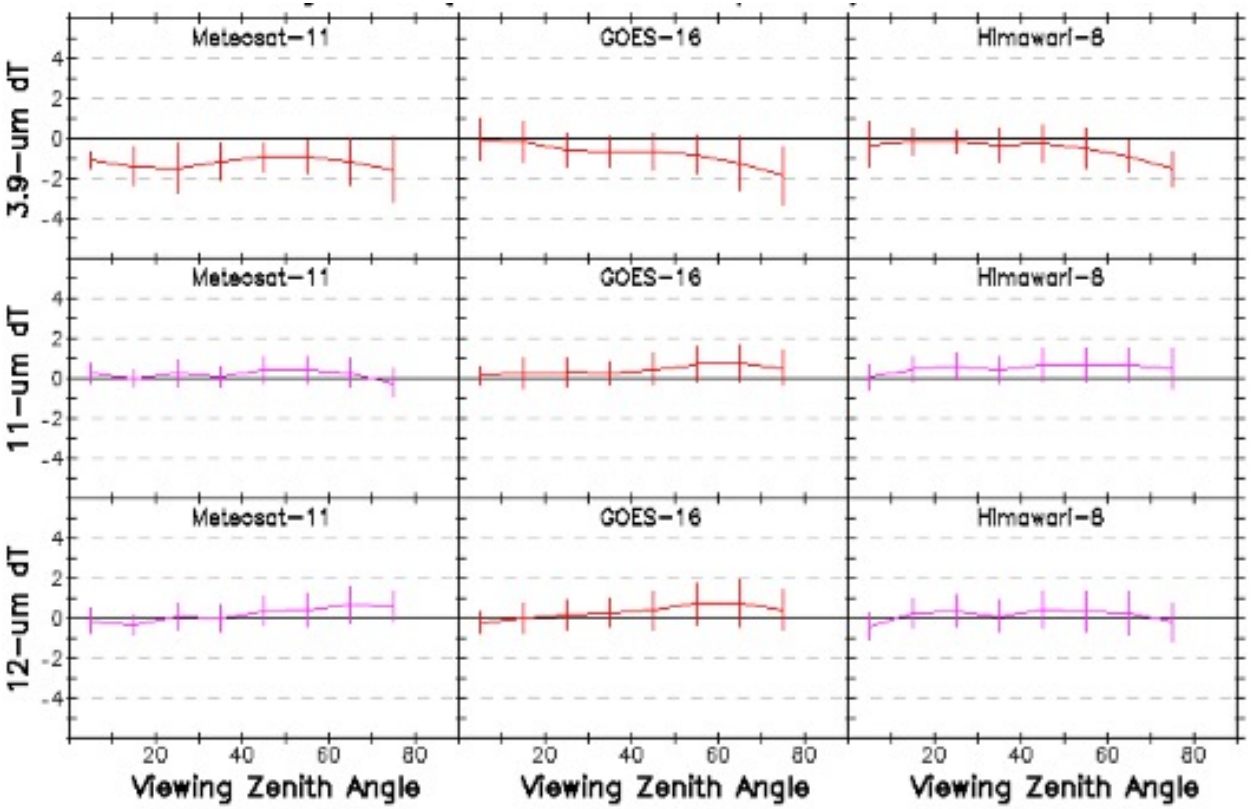
Meteosat-11 GOES-16 Himawari-8



Errors > 1K

Updated for Ed5

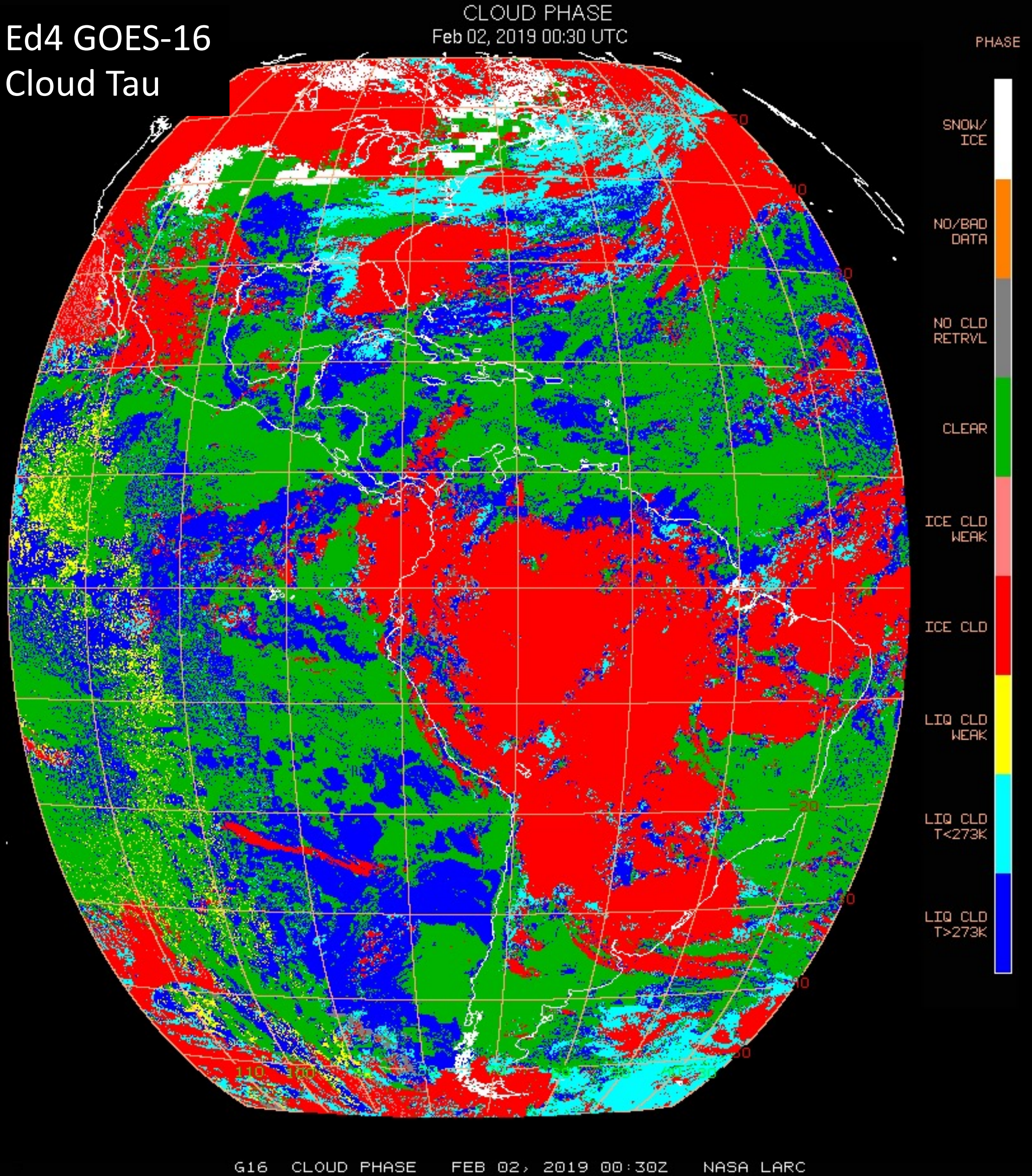
Meteosat-11 GOES-16 Himawari-8



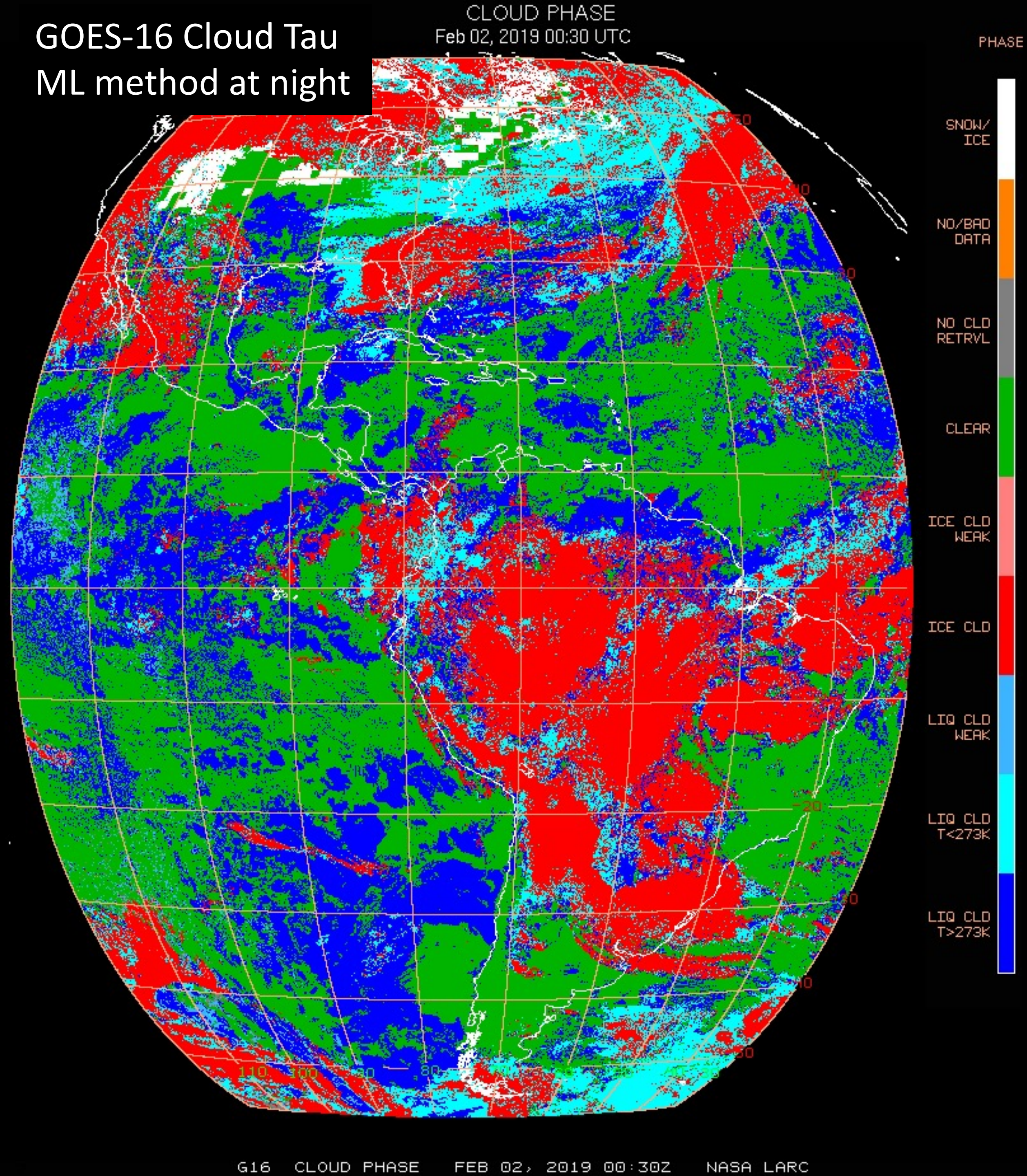
Errors < ~ 0.2 K for 11, 12 µm

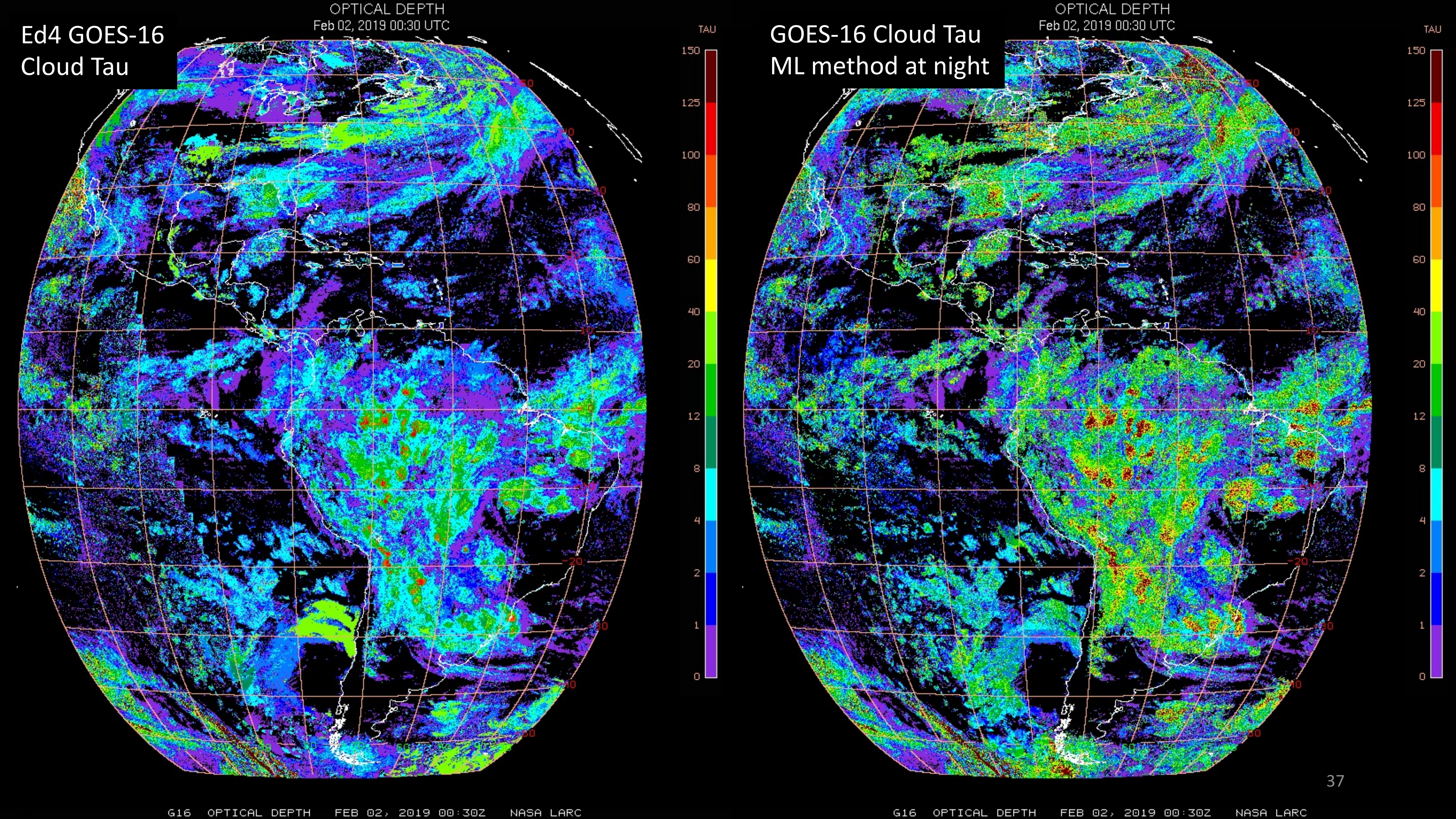
Daytime 3.7 solar component needs work

Ed4 GOES-16 Cloud Tau



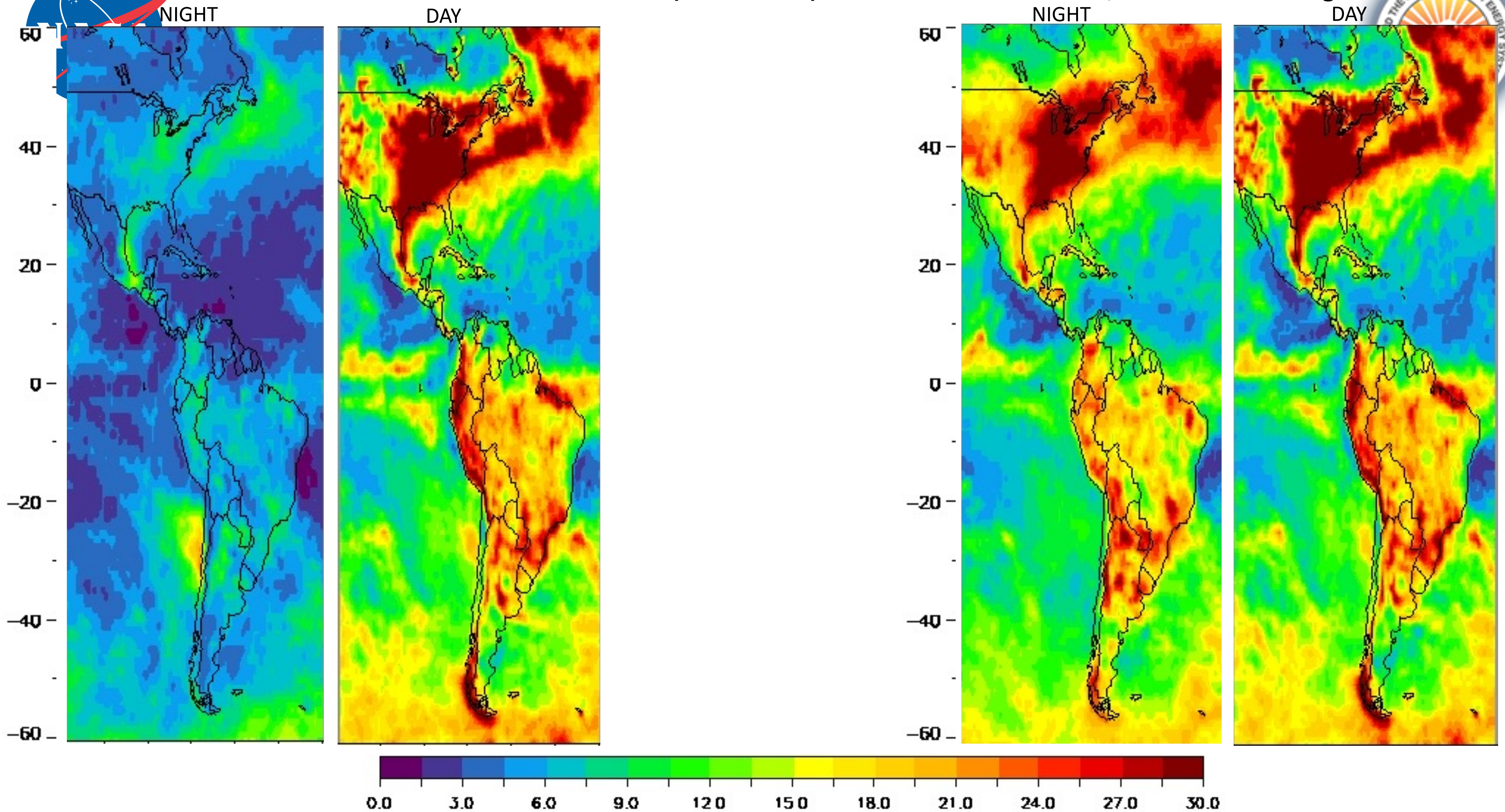
GOES-16 Cloud Tau
ML method at night





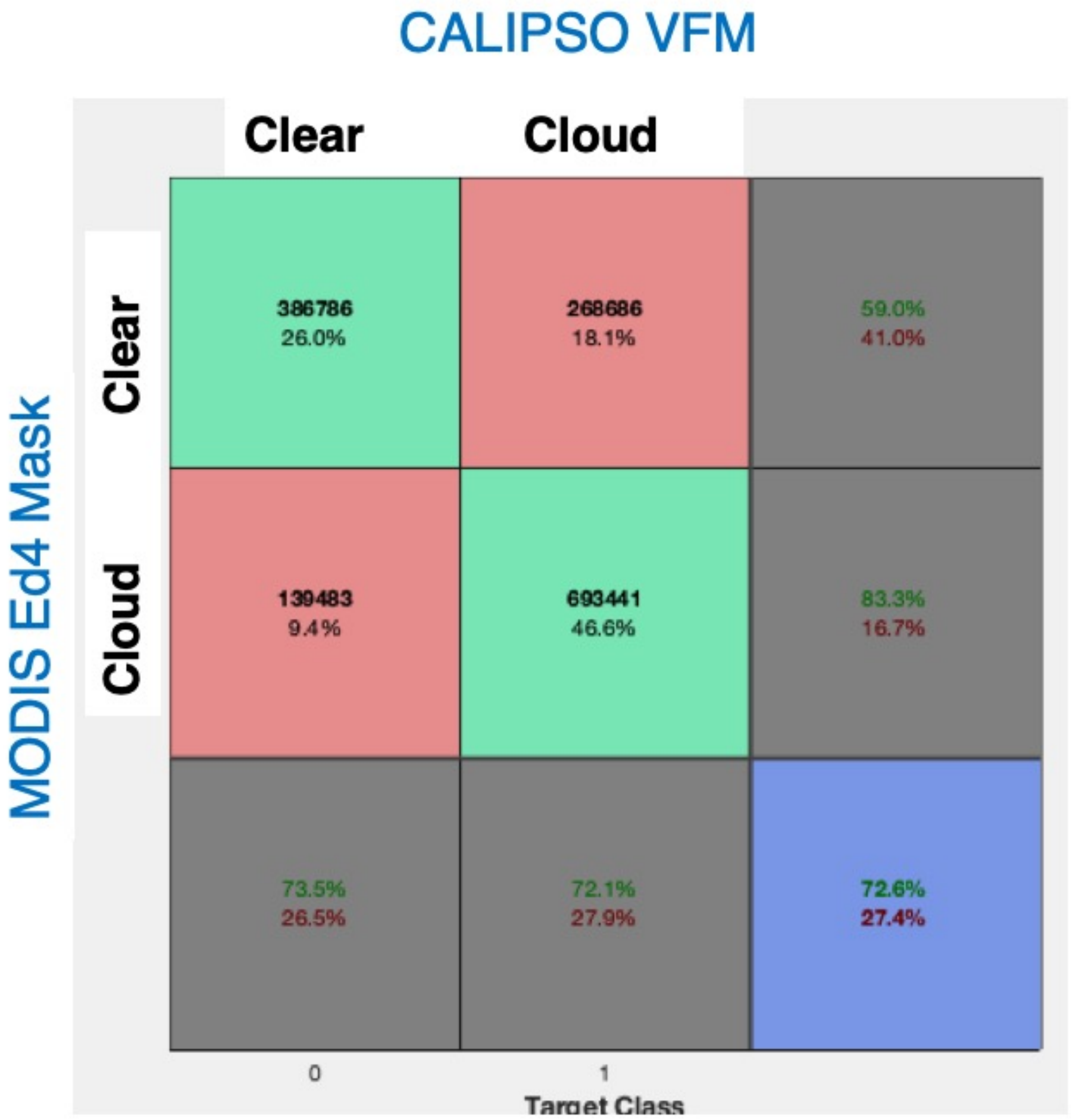
Ed4 GOES-16
Cloud Tau
OPTICAL DEPTH
Feb 02, 2019 00:30 UTC
TAU
150
125
100
80
60
40
20
12
8
4
2
1
0
G16 OPTICAL DEPTH FEB 02, 2019 00:30Z NASA LARC
GOES-16 Cloud Tau
ML method at night
OPTICAL DEPTH
Feb 02, 2019 00:30 UTC
TAU
150
125
100
80
60
40
20
12
8
4
2
1
0
G16 OPTICAL DEPTH FEB 02, 2019 00:30Z NASA LARC

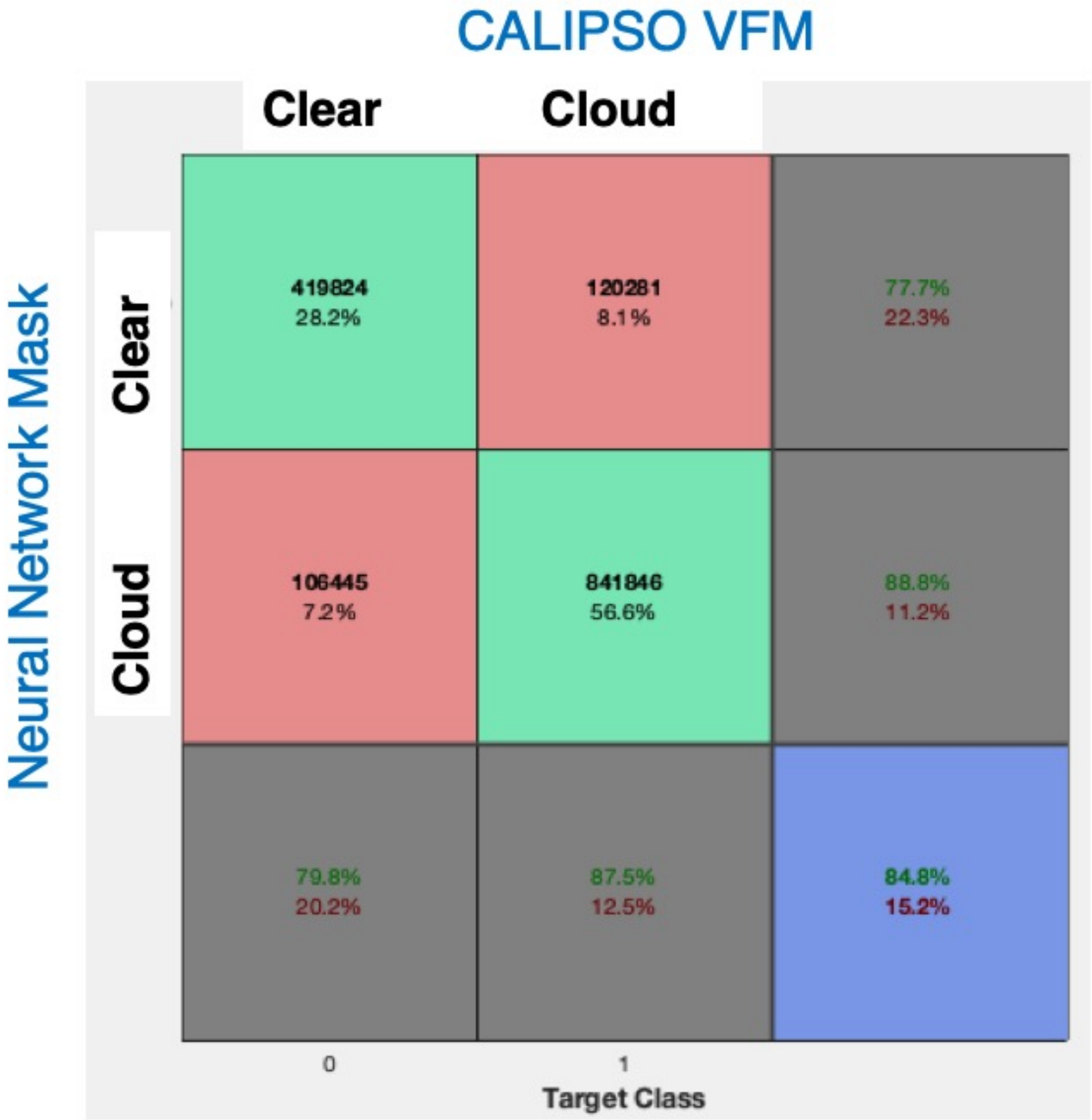
Total Optical Depth, Feb 2019



Aqua, 200807

Night Time, Antarctica (IGBP = 15, Permanent Snow)





NN Training without 6.7 & CO2 channels

Summary

- A new VIIRS edition (Ed1B) for NOAA 20 clouds has been developed to improve consistency with Ed4 that could be used to extend the Aqua CDR prior to the release of Ed5 (or to fill gaps, e.g Aug 2020).
- In some significant ways, Ed1B VIIRS clouds are found to be more consistent with Ed4 MODIS than we found for Ed1A.
- Good progress was made on work toward Edition 5 including the development of a new processing framework, improved atmospheric corrections, work to improve clear sky radiances for the LEO and GEO cloud algorithms and much more.
- We're experimenting with machine learning to try and address difficult problems that have been hard to resolve with traditional passive satellite remote sensing. More work is planned to further develop and evaluate these with independent data under a wide range of conditions and further explore their potential for CERES.

QUESTIONS ?